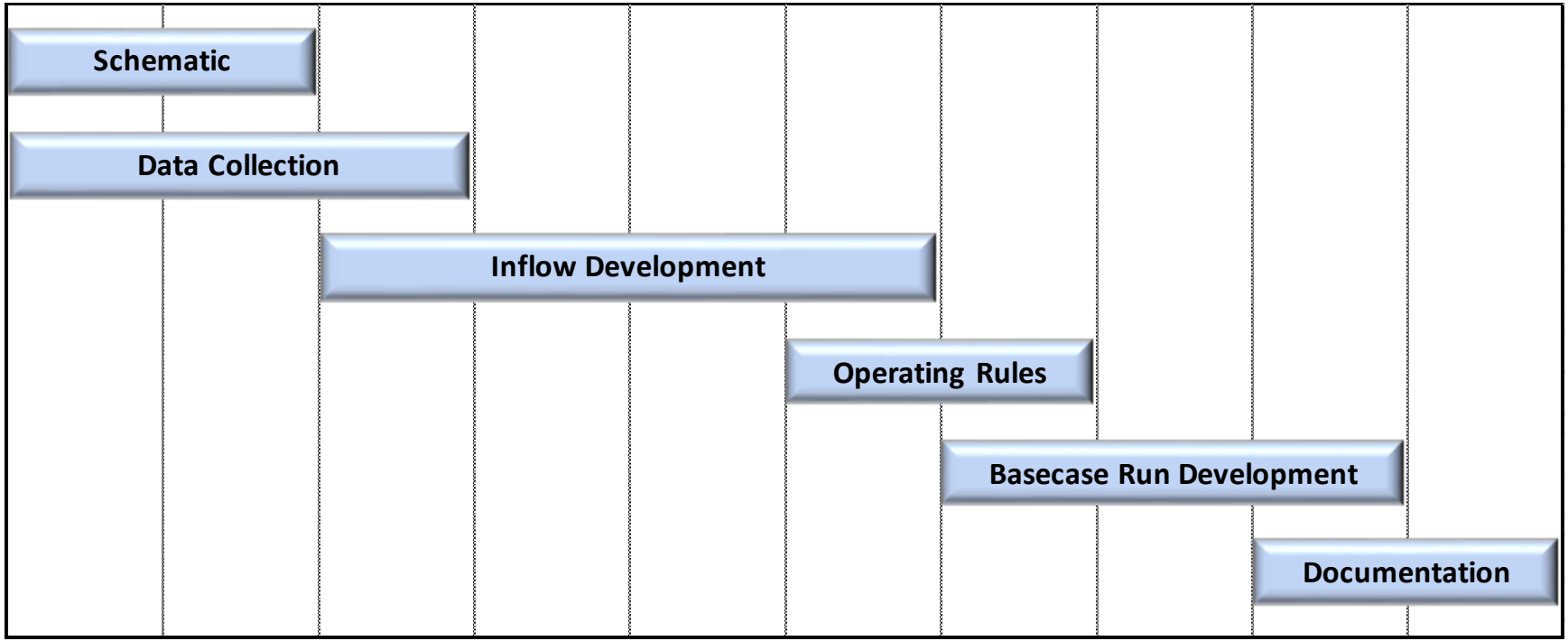
Hazen

DEQ
NORTH CAROLINA
Department of Environmental Quality


# Model Overview – Yadkin-Pee Dee/Lumber River Basin Hydrologic Model

December 11, 2020

# Project Timeline



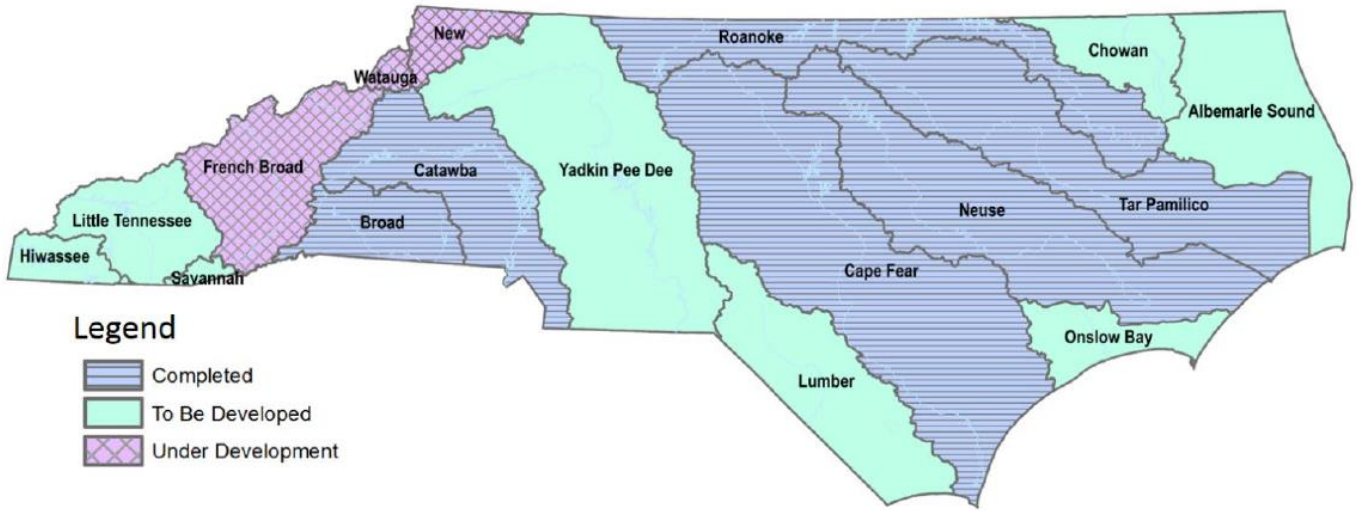
# Project Acknowledgement


- Generous financial support by DWR
  - **Tom Fransen, Pam Behm – DWR**
- Generous time commitment from stakeholders, especially TRC members
  - **Neela Sarwar, Pam Behm – DWR; Jonathan Williams – HDR; Tim Poole – Cube Carolinas; Ed Bruce – Duke Energy; Tony Young – Corps of Engineers; Aubrey Lofton – Union County; Curtis Weaver – USGS; Chris Goudreau – NC Wildlife Resources Commission; Brian Fannon – Yadkin Riverkeeper; Jefferson Currie – Lumber Riverkeeper**
- Supporting documentation and data from the YPDWMG and its members (utilities and power companies)

# Meetings and Purpose

- Kickoff Meeting (Mar. 4)
- TRC #1 (Sept. 2):  model development overview, plus schematic review
- TRC #2 (Oct. 5):  review inflows
- TRC #3 (Nov.12):  review basecase run results (including inflows and operating logic)
- Model Overview [today]:  provide model overview, applications of model, and results
- Training (mid-Jan):  virtual demonstration of OASIS model and scenarios

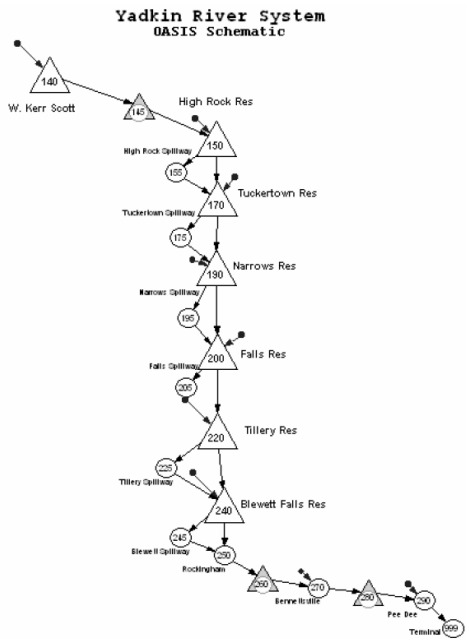
# NC DWR Basin-Wide Modeling Initiative (Shown to YPDWMG in Nov.2016)

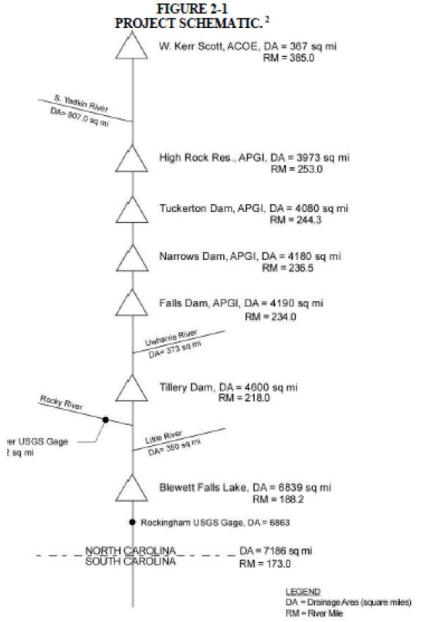



CHEOPS model in Catawba; OASIS model elsewhere. First DWR basin model was in the 1970s for the Yadkin Capacity Use Area Study.

# Major Modeling and Water Use Assessment in the Yadkin

- Relicensing
  - **Yadkin Project: Alcoa (APGI) early 2000s; new license issued in 2017 to now Cube Hydro Carolinas. OASIS developed by HydroLogics (now Hazen)**
  - **Yadkin-Pee Dee Project: Progress Energy mid 2000s; new license issued in 2015 to now Duke Energy. CHEOPS developed by DTA (now HDR).**
- IBT Permitting
  - **Concord/Kannapolis: OASIS used by NC DWR.**
  - **Union County: CHEOPS used by HDR.**

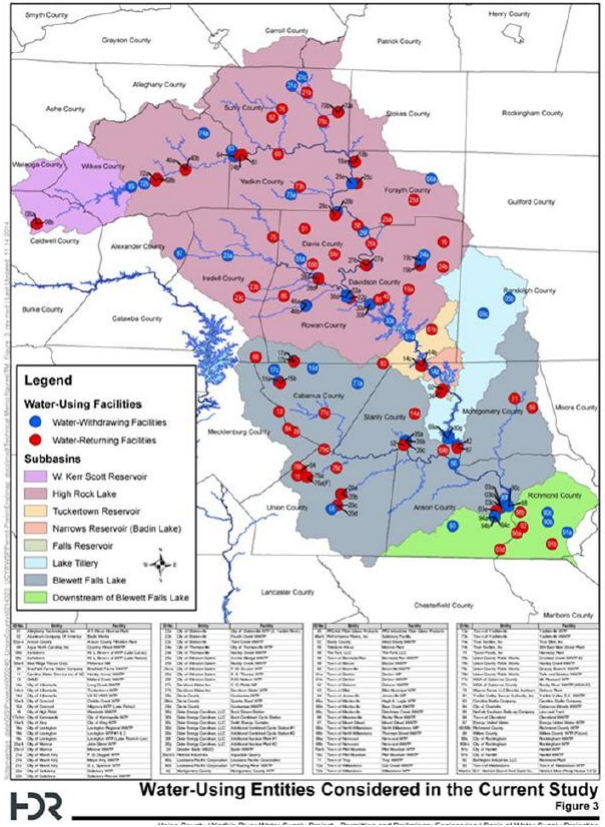


# Major Modeling and Water Use Assessment in the Yadkin (cont'd.)

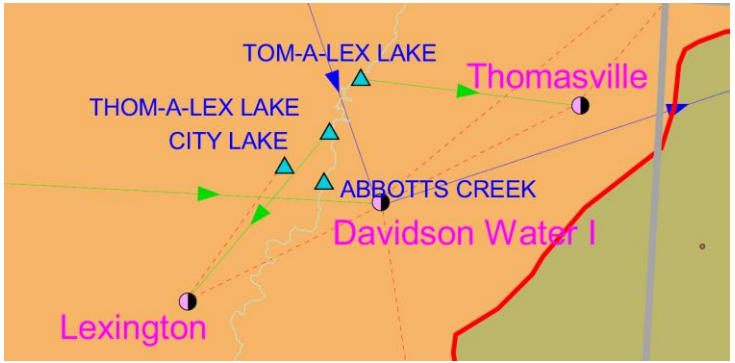
## Yadkin-Pee Dee Water Use

- Water Use Study - 2014
  - Part of Union County IBT process
  - Basin-wide projections (W. Kerr Scott to SC state line)
  - 2010-2012 (base) to 2060
- YPDWMG – 2019 Updates
  - Part of Water Resources Plan development
  - 2017 (base) to 2070

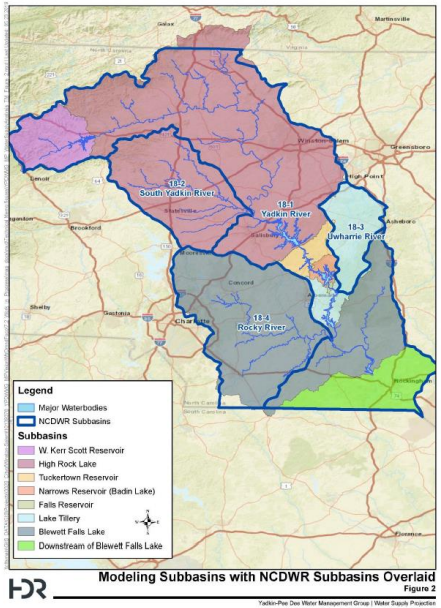


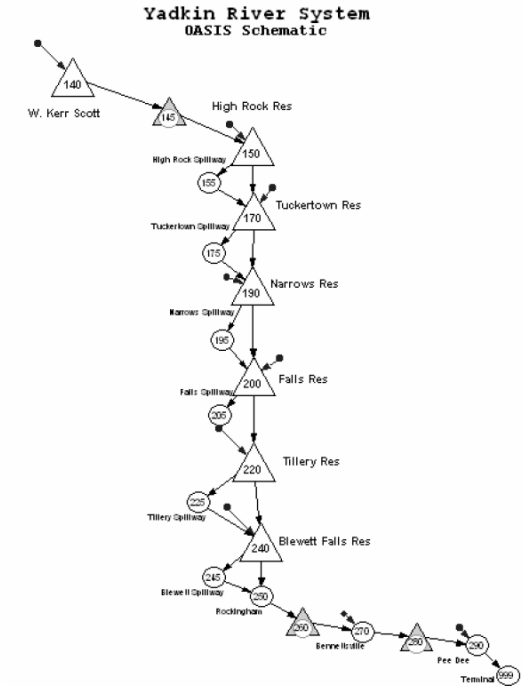

From HDR presentation to DMAG in 2019

# The Next Model Iteration

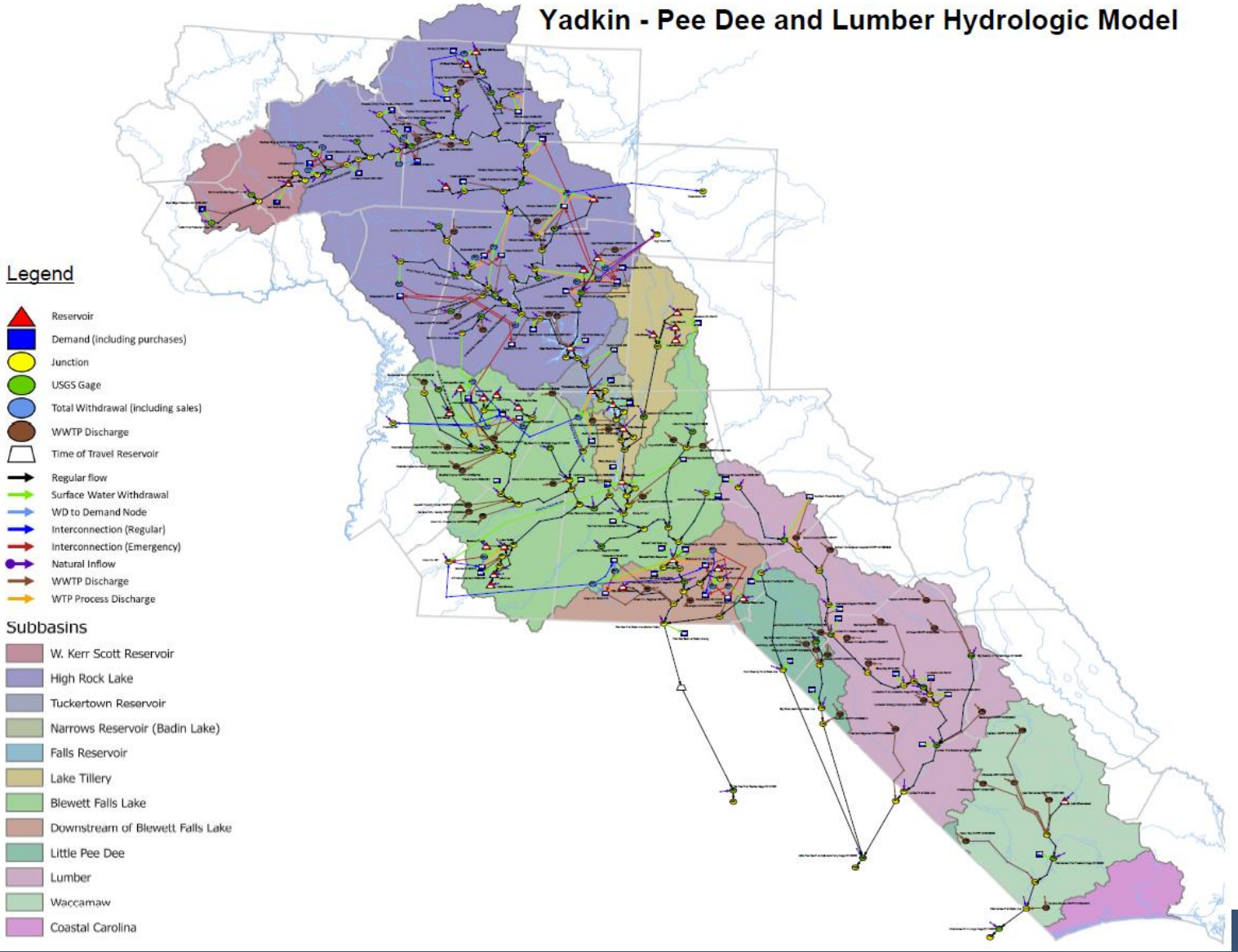



Reservoir Catchments and
DWR Subbasins

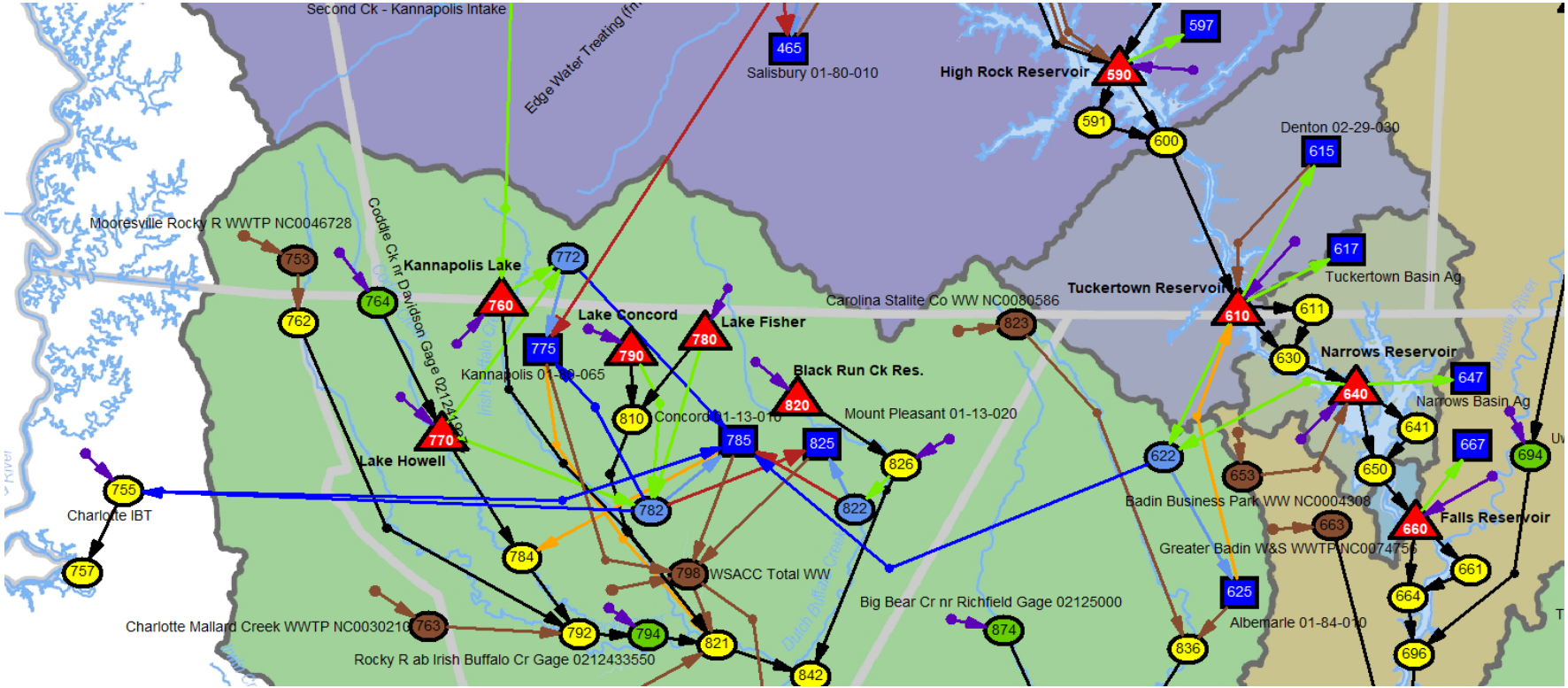


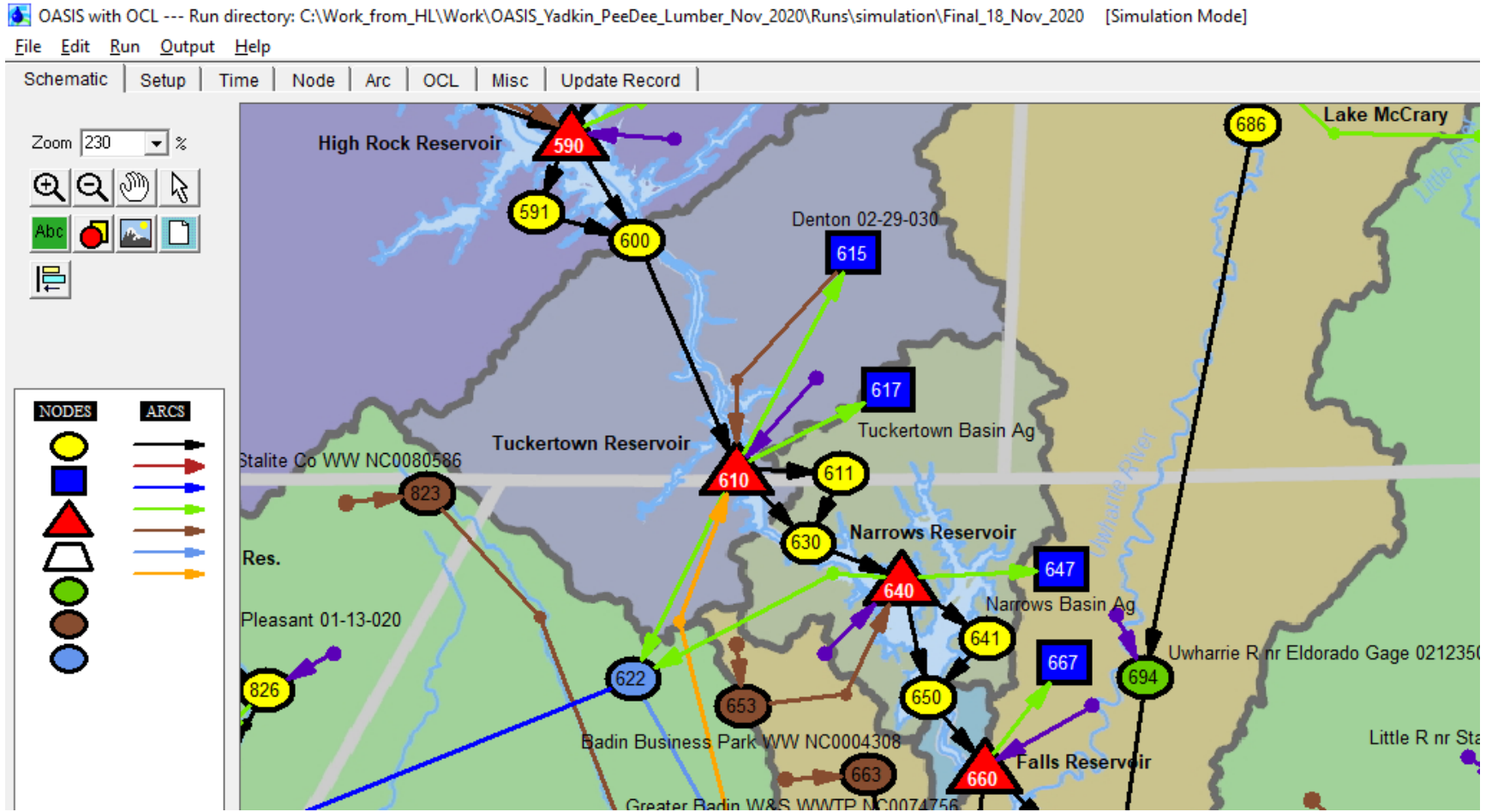
# Yadkin - Pee Dee and Lumber Hydrologic Model



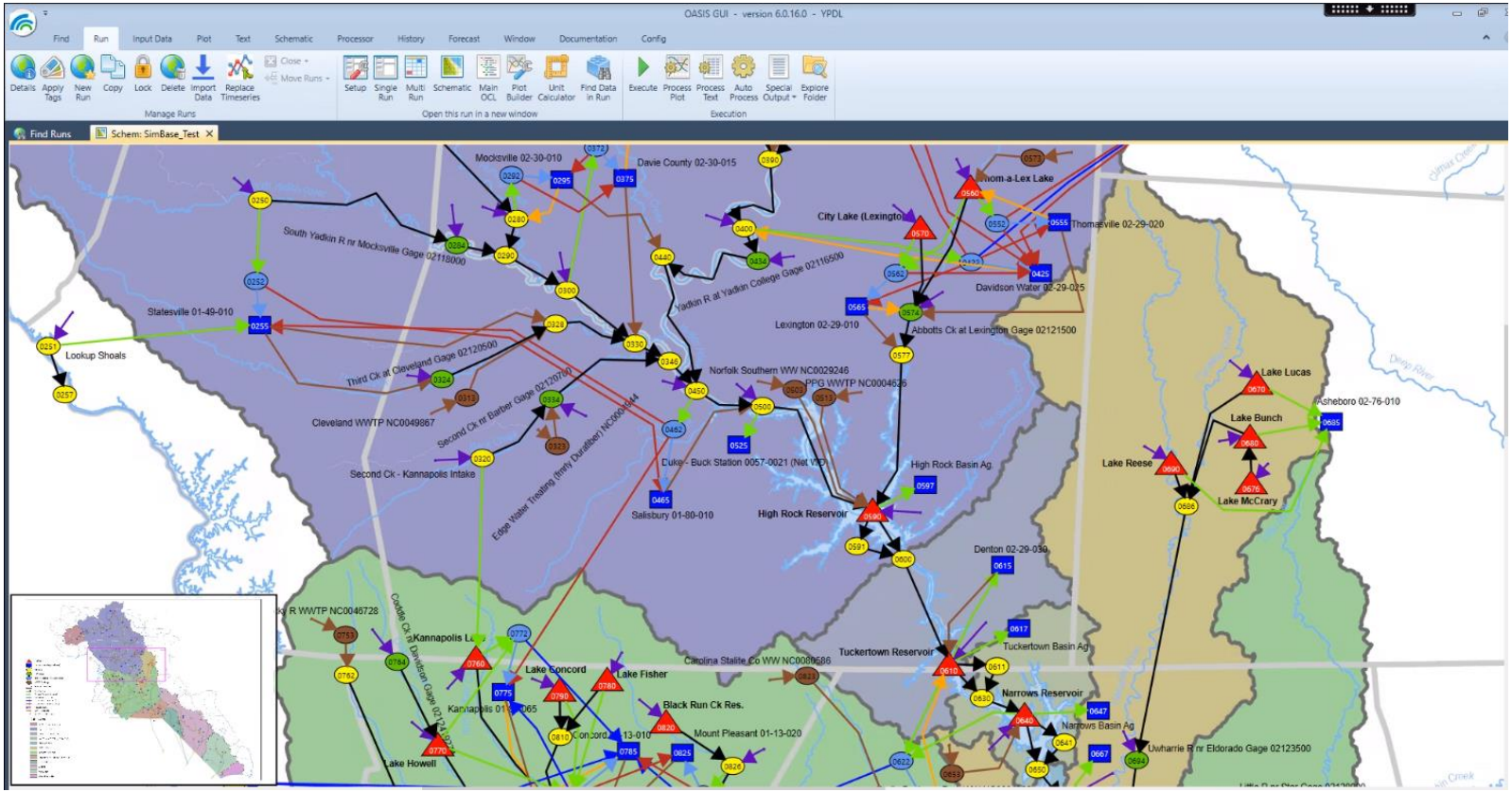
# Schematic Detail



# Classic OASIS



# New OASIS


OASIS GUI - version 6.0.16.0 - YPDL
Find Runs
Schem: SimBase_Test
Mocksville 02-30-010
Davie County 02-30-015
South Yadkin R nr Mocksville Gage 02118000
Statesville 01-49-010
Lookup Shoals
Third Ck at Cleveland Gage 02120500
Cleveland WWTP NC0049867
Second Ck nr Barber Gage 02120780
Second Ck - Kannapolis Intake
Edge Water Treating (formly Duratherm) NC0001244
Yadkin R at Yadkin College Gage 02116500
Norfolk Southern WW NC0029246
PPG WWTP NC0004626
Duke - Buck Station 0057-0021 (Net YD)
Salisbury 01-80-010
High Rock Reservoir
High Rock Basin Ag
City Lake (Lexington)
Thomasville 02-29-020
Davidson Water 02-29-025
Lexington 02-29-010
Abbotts Ck at Lexington Gage 02121500
Lake Lucas
Asheboro 02-76-010
Lake Bunch
Lake Reese
Lake McCrary
Denton 02-29-030
Tuckertown Reservoir
Tuckertown Basin Ag
Carolina Stalite Co WW NC0000586
Narrows Reservoir
Narrows Basin Ag
Uwharrie R nr Eldorado Gage 02123500
Kannapolis Lake
Lake Concord
Lake Fisher
Black Run Ck Res.
Mount Pleasant 01-13-020
Lake Howell

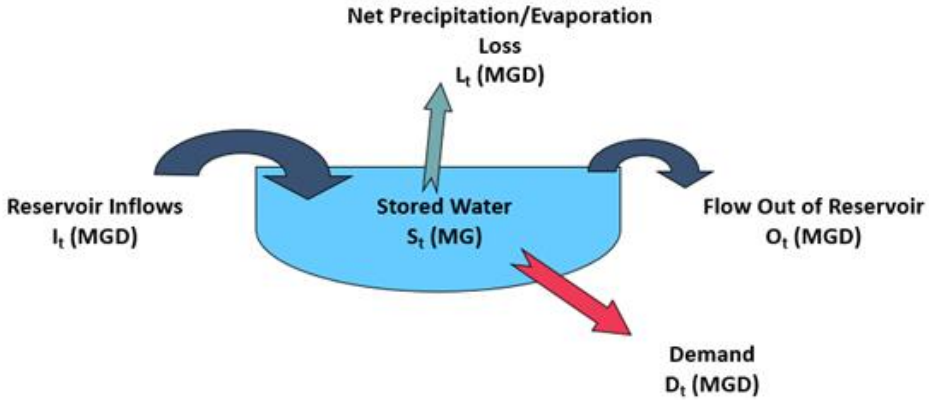
# Refinements with YPDL OASIS Model*

- Inflow dataset
  - **Relies on longer inflow record to capture additional droughts**
  - **Uses many more gages in the basin (made possible by extensive data unimpairment), including key gages on the mainstem (Yadkin College, High Rock, and Rockingham), plus inflows derived from historic operating data for Kerr Scott and High Rock**
  - **Ensures a monthly match with unregulated gage flows**
  - **Automated update to keep inflows current and allow for operations and real-time forecasting**
- Ag water use developed explicitly around water use needs of certain crops relative to rainfall and needs of livestock
  - **Future demands can be updated automatically as crop patterns and livestock counts change**
- Tracking the flow of water
  - **Extensive interconnections (regular, emergency, and/or IBTs) provided**
- Automated safe yield routines
- Switch to turn on and off all drought plans, including LIP
- Automated demand adjustment (uniformly applied to all demand nodes)
  - **WW returns linked to demand nodes get adjusted automatically**

* Common to all OASIS models for NC basins

# Uses of the Model

- Water budgeting (supply and demand) for all significant users, over a long, **fully** unimpaired inflow record
  - **Prior models did not capture this level of detail, including interconnections**
  - **Example: Monroe is one of dozens of systems that can now be evaluated, capturing the critical droughts of record for each (for Monroe, 1950-51)**

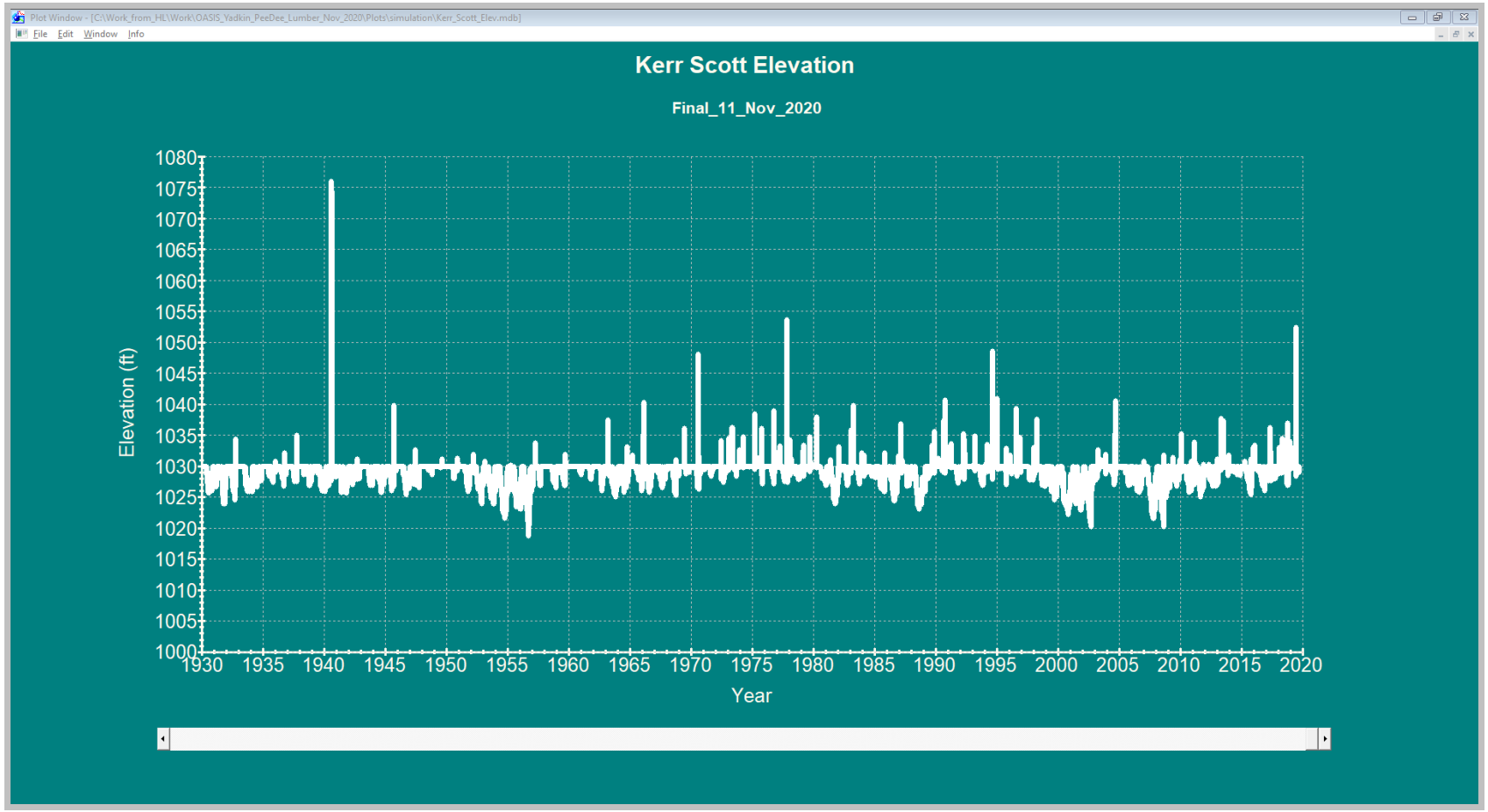



$S_t = S_{t-1} + I_t - D_t - L_t - O_t$, where $S_{t-1}$ = yesterday's storage

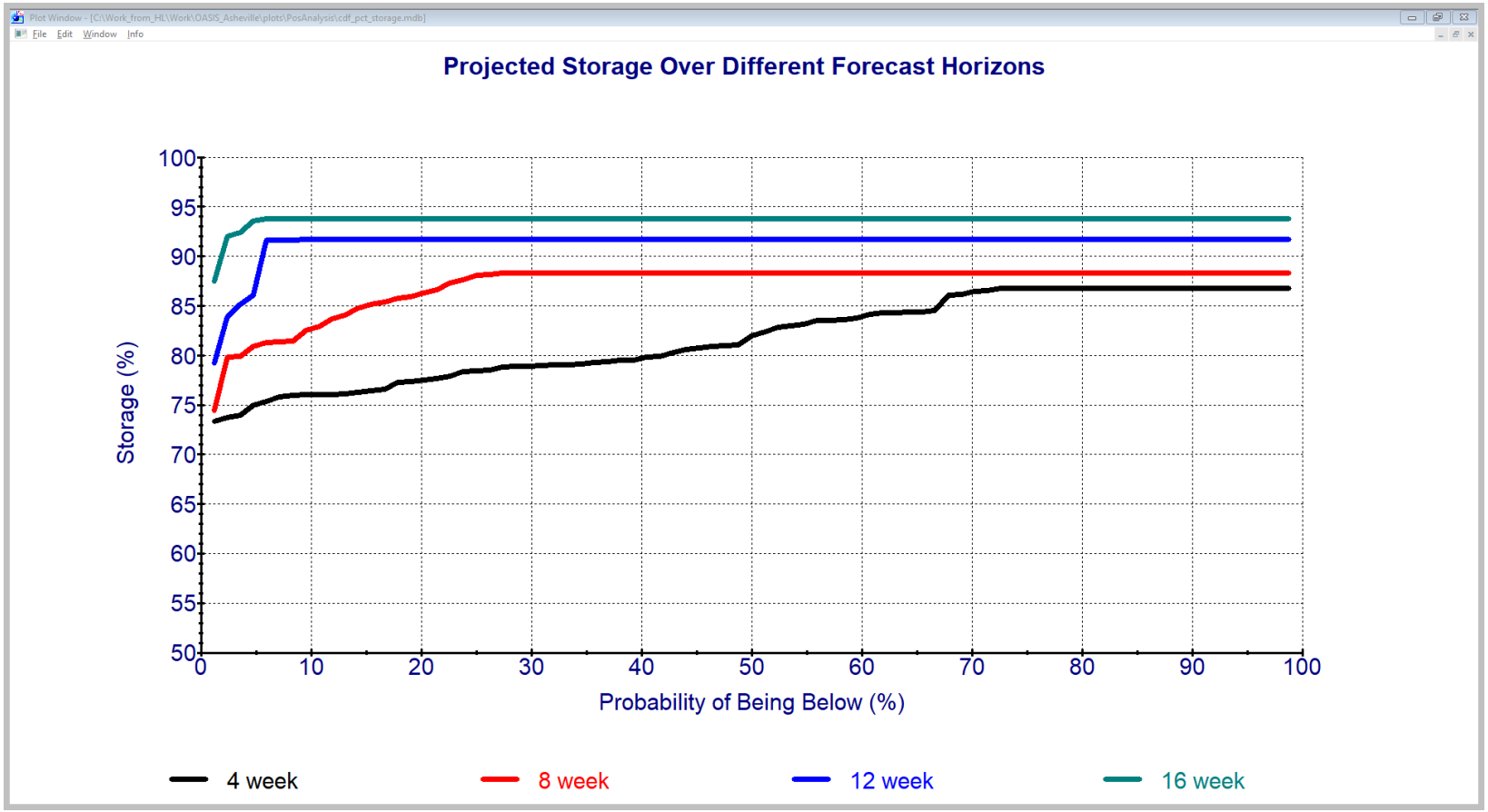
# Uses of the Model (cont'd.)

- Drought plan assessment
  - **Develop improved operating rules, including probability-based drought triggers**
  - **Drought exercises for the YPDWMG**
- Impacts of interbasin transfers
- Planning and operations of facilities (including hydro)
- Ecological flow impacts
- Forecasting of inflows and reservoir storage
- Impacts of reservoir rule curves and storage on downstream flows
  - **Not a hydraulic model, but can be used for assessing flood control benefits**
  - **Note: routing provided to improve flow estimation to High Rock (based on one day lag of Kerr Scott change in storage) and South Carolina Pee Dee gage (based on two day lag from Rockingham)**
  - **Generally, routing is not needed because of significant local resolution in inflows due to wide network of gaging stations used in inflow development**

# Simulation Over Historic Inflow Record



# Forecast Run – Storage Projection Sample



# Uses of the Model of Interest to the YPDWMG

Table 1-1. Selected scenarios for further analysis

| Scenario Category | Scenario |
|---|---|
| Climate/ Environmental Shifts | 1. Drought reduces supply |
| | 2. Storms become more infrequent and intense |
| | 3. Increase in sedimentation decreases reservoir storage and/or restricts intakes |
| General Policy Shift | 4. New policy or regulation requires an increased quality of wastewater discharge (e.g. High Rock Lake Nutrient Management) |
| | 5. W. Kerr Scott Reservoir revised flow protocol |
| | 6. New regulation/ policy requires an increase in the price of water, which decreases demand |
| Industrial | 7. Increase in industry wastewater production (Ex. Poultry processing), resulting in degraded water quality |
| Public Behavioral Shifts | 8. Increased population growth within the region, which increases demand |
| | 9. Increased regionalization as people move to urban centers and become less reliant on well water, which increases demand |
| | 10. Changes to IBT, which allows more water to leave the basin |

Table 1-2. SAC Selected scenarios for further analysis

| Scenario Category | Scenario |
|---|---|
| Land Use Change | 1. Reduction in forested land could lead to an increase of runoff of nutrients and contaminants |
| Climate/ Environmental Shifts | 2. Increase in peak storm flows carry more sediment and nutrients |
| | 3. Evaluate the potential for improving the flood management capabilities to mitigate the impacts of future flooding throughout the Basin (including South Carolina) |

# Uses Could Include Other Scenarios Considered Before

- Union County IBT analysis by HDR

  - No additional IBT for Union County's YRWSP
  - Future (Year 2050) basin-wide water demands (withdrawals/returns)
  - Includes future impact of climate change in future years resulting in an increased temperature of 2.3 deg F (0.6 deg F increase per decade) and lake surface evaporation increases of 7.8% (equivalent to an increase of 2% per decade), as compared to the 2012 baseline. This impact is consistent with the climate change impact considered by the Catawba-Wateree Water Management Group in preparation of the Catawba-Wateree Water Supply Master Plan baseline planning scenario, and is consistent with modeled climate change scenarios for this region of the United States.

**A1-2012 (Alternative 1-2012)**

  - 23 mgd (maximum month daily average demand (MMDD)) IBT (net) from Pee Dee River, withdrawn at Lake Tillery
  - Current (Year 2012) basin-wide water demand (withdrawals/returns) with Union County YRWSP projected Year 2050 IBT
  - Used to compare effects of Alternative 1 to BLY-2012 (Yadkin Baseline-2012) scenario under current basin-wide water demand.

**A1-2050 (Alternative 1-2050)**

http://cubecarolinas.com/wp-content/uploads/2019/12/2019-12-December-Check.pdf

# OASIS Model Accessibility

- Available to all stakeholders through accounts to NC DWR server
- Model is a living document, meant to be easily updated
  - **Provided with automated inflow update**
  - **Changes to system plumbing or operating rules can easily be made**
  - **Adding additional historical data for inflow/operating rule verification**
- Model is user-friendly, with easy to define performance measures like elevation, flow, and generation, along with probability tables and plots and user-defined level of impact (thresholds defining minor or major) like for Union County IBT analysis.
- Model is well documented, including historical detail on hydro operations between the old license, “interim” license, and new licenses

```
//  File is Mainstem_Operations.ocl, which has the coding to handle the operations from the Yadkin Projects (High Rock down to Falls)
// and the Yadkin-Pee Dee Projects (Tillery and Blewett Falls).

// The details are defined in the 50-year FERC licenses for the 212.5 MW Yadkin Hydro Project (Cube) [FERC Project No. 2197, or P-2197]
// and the 108.6 MW Yadkin-Pee Dee Hydro Project (Duke Energy) [P-2206] as well as in the drought plans of utilities bound by it
// because of withdrawals from the reservoirs (including IBTs) like Concord and Kannapolis.
```

- Tutorial for creating and modifying runs and adjusting input and output

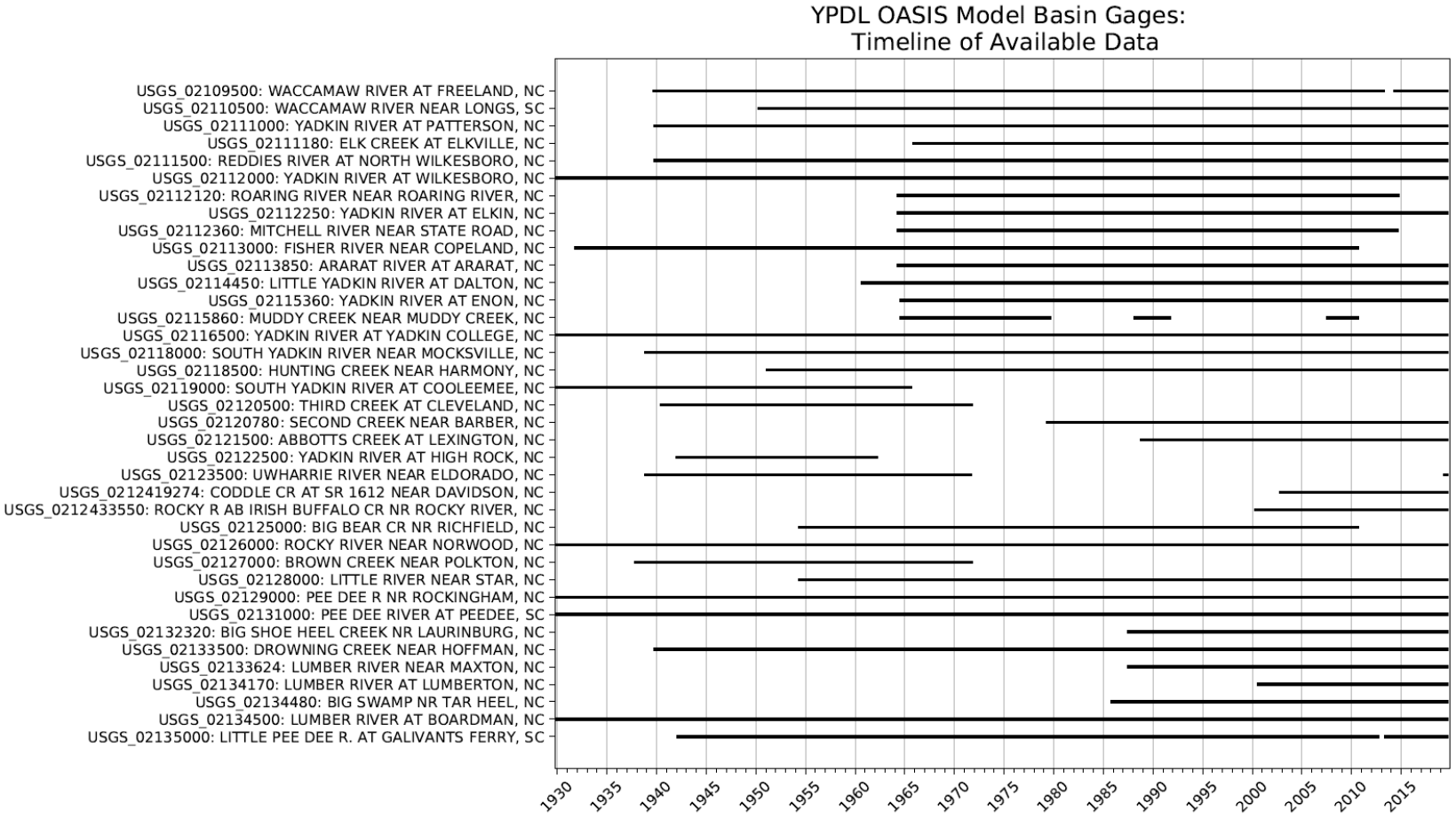
# Model Development Process

- Develop schematic
  - **Yadkin Pee Dee: node numbers <= 999**
  - **Lumber: node numbers >= 1000**
  - **Nodes assigned ending number depending on classification (e.g., reservoirs = __0)**
  - **Geographic extent: from headwaters to where rivers join the Pee Dee in South Carolina, with local resolution in North Carolina**
  - **Provide consistency with HDR's YPDWMG Demand Projections (Tech Memo Update - July 2019) regarding entities, amounts, and sub-basin classifications**
  - **Surface water only (either withdrawals or WW discharges), with facilities in operation or anticipated in the future**
- Compile streamflow and precipitation gaging data
- Collect impairment data (withdrawals and WW discharges >= 0.1 mgd for M&I, plus withdrawals for Ag), plus reservoir change in contents, from databases and information from entities
- Hindcast impairments back to 1930 (start of inflow record), adjusted for facility start/stop dates
- Develop unimpaired inflows on monthly basis
  - **Match at gages, meaning error is embedded in the impairments**
  - **Disaggregate to daily inflows using mostly reference gages**
- Incorporate operating rules
- Develop basecase run (current conditions) – daily timestep, 1930 to Sept. 2019 (with provisional inflow updates to allow for real-time drought forecasting)

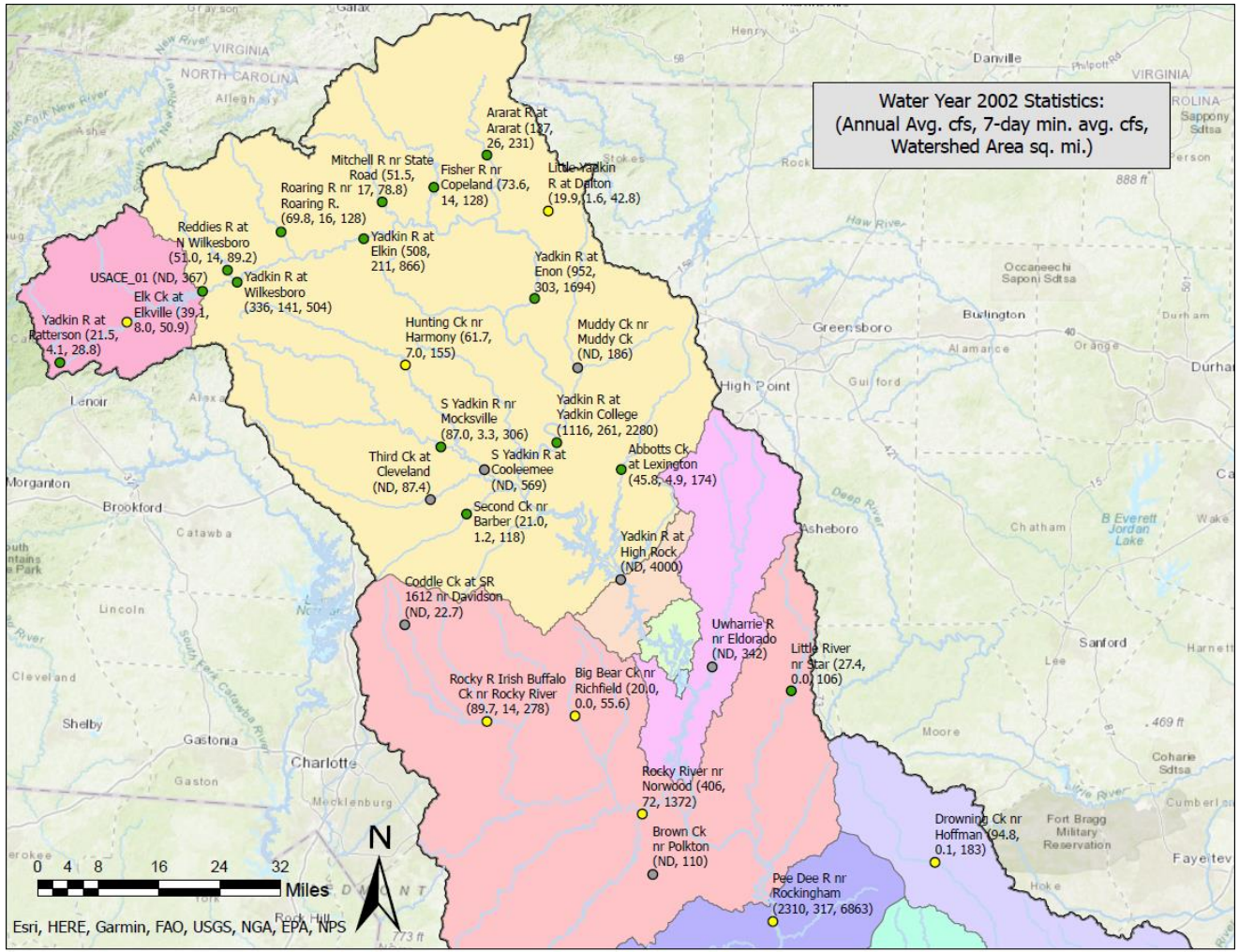
# Schematic

- Inflow nodes:  80 in YPD, 20 in Lumber
  - **USGS gages = 36**
- Reservoir nodes:  30 (all but one in the YPD)
- M&I demand nodes:  40 in YPD, 5 in Lumber
- Agricultural demand nodes:  8 in YPD, 5 in Lumber
- WW return arcs linked to demand nodes:  35 in YPD, 5 in Lumber
- WTP process return arcs linked to demand nodes:  15 in YPD, 1 in Lumber
- WW independent return nodes:  25 in YPD, 20 in Lumber
- Interconnection arcs:  15 regular, 30 emergency, including IBTs
- Future intakes

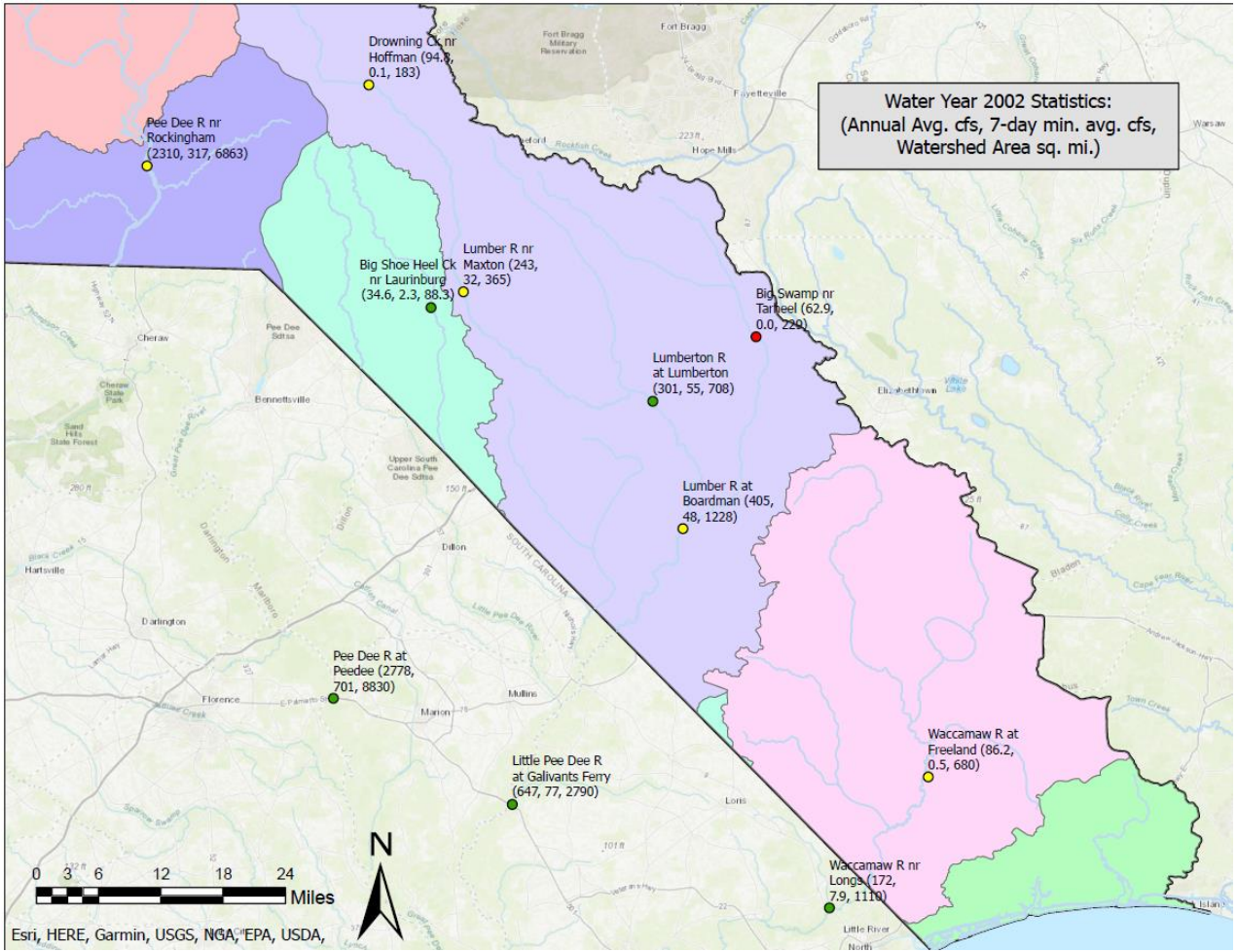
# Compile Gaging Data (for the USGS-designated “Pee Dee River Basin”



# Gage Map


Water Year 2002 Statistics:
(Annual Avg. cfs, 7-day min. avg. cfs, Watershed Area sq. mi.)
Ararat R at Ararat (127, 26, 231)
Mitchell R nr State Road (51.5, 17, 78.8)
Fisher R nr Copeland (73.6, 14, 128)
Little Yadkin R at Dalton (19.9, 1.6, 42.8)
Roaring R nr Roaring R. (69.8, 16, 128)
Reddies R at N Wilkesboro (51.0, 14, 89.2)
Yadkin R at Elkin (508, 211, 866)
Yadkin R at Enon (952, 303, 1694)
USACE_01 (ND, 367)
Yadkin R at Wilkesboro (336, 141, 504)
Elk Ck at Elkville (39.1, 8.0, 50.9)
Yadkin R at Patterson (21.5, 4.1, 28.8)
Hunting Ck nr Harmony (61.7, 7.0, 155)
Muddy Ck nr Muddy Ck (ND, 186)
S Yadkin R nr Mocksville (87.0, 3.3, 306)
Yadkin R at Yadkin College (1116, 261, 2280)
Third Ck at Cleveland (ND, 87.4)
S Yadkin R at Cooleemee (ND, 569)
Abbotts Ck at Lexington (45.8, 4.9, 174)
Second Ck nr Barber (21.0, 1.2, 118)
Yadkin R at High Rock (ND, 4000)
Coddle Ck at SR 1612 nr Davidson (ND, 22.7)
Uwharrie R nr Eldorado (ND, 342)
Little River nr Star (27.4, 0.0, 106)
Rocky R Irish Buffalo Ck nr Rocky River (89.7, 14, 278)
Big Bear Ck nr Richfield (20.0, 0.0, 55.6)
Rocky River nr Norwood (406, 72, 1372)
Brown Ck nr Polkton (ND, 110)
Drowning Ck nr Hoffman (94.8, 0.1, 183)
Pee Dee R nr Rockingham (2310, 317, 6863)
N
0 4 8 16 24 32
Miles
Esri, HERE, Garmin, FAO, USGS, NGA, EPA, NPS

# Gage Map


Water Year 2002 Statistics:
(Annual Avg. cfs, 7-day min. avg. cfs,
Watershed Area sq. mi.)
Drowning Ck nr Hoffman (94.8, 0.1, 183)
Pee Dee R nr Rockingham (2310, 317, 6863)
Big Shoe Heel Ck nr Laurinburg (34.6, 2.3, 88.3)
Lumber R nr Maxton (243, 32, 365)
Big Swamp nr Tarheel (62.9, 0.0, 229)
Lumberton R at Lumberton (301, 55, 708)
Lumber R at Boardman (405, 48, 1228)
Pee Dee R at Peedee (2778, 701, 8830)
Little Pee Dee R at Galivants Ferry (647, 77, 2790)
Waccamaw R at Freeland (86.2, 0.5, 680)
Waccamaw R nr Longs (172, 7.9, 1110)
N
0 3 6 12 18 24
Miles
Esri, HERE, Garmin, USGS, NGA, EPA, USDA,

# Compile Impairments

- Water withdrawals*
  - **Public: LWSP database (1997 through present, with some gaps, on a monthly basis); data collected through 2019.**
  - **Industrial (including power plants): WWATR database (1999 through present, with some gaps, on a monthly basis); data collected through 2018**
    - *Power plants evaluated as "net" withdrawal for consistency with HDR study (= water – wastewater use) since water and WW discharges are in close proximity*
  - **Agriculture: from USDA census data on irrigated crop acreage and livestock counts, + USGS surveys. Key irrigated crops incorporate water use curves in which irrigation use is dependent on rainfall. Use computed at county level (NC, but also VA and SC) and, in most cases, allocated to each subbasin based on percent coverage.**
  - **Additional data from entities will supersede information from databases**
- Wastewater discharges
  - **Public: NPDES database (early 1990s through present on a monthly basis); data collected through 2018. Some information provided from LWSP databases.**
  - **Industrial: NPDES**
    - *Occasionally, facilities have multiple outfalls which were aggregated to get total discharge*
  - **Additional data from entities will supersede information from databases**
  - **Some entities include NCG (stormwater) permits; stormwater excluded**
- Reservoir change in contents and associated net evaporation (using surface area x net evap rate)
  - **USGS reports provide key information on mainstem reservoir change in contents**
  - **Supplemented with requests of utilities and power companies**

* NC Statute in 1991 required WD registration, updated every 5 years, for non-Ag uses > 0.1 mgd (Ag use is > 1 mgd) or transfers from one basin to another. In 2007, requirement for annual water use reporting.

# Criteria For Entities Being Included in the Inflow Unimpairment

- All those with historic surface water withdrawals from the basin > 0.1 mgd annual average (Ag not included)
  - **Seasonality considered when annual average < 0.1 mgd**
  - **Only Lumberton had significant GW withdrawal as well as SW withdrawal. This was accounted for.**
- All those with historic surface water WW discharges in the basin > 0.1 mgd annual average
  - **Also applies to entities that withdraw only GW**
  - **Same note as above on seasonality**

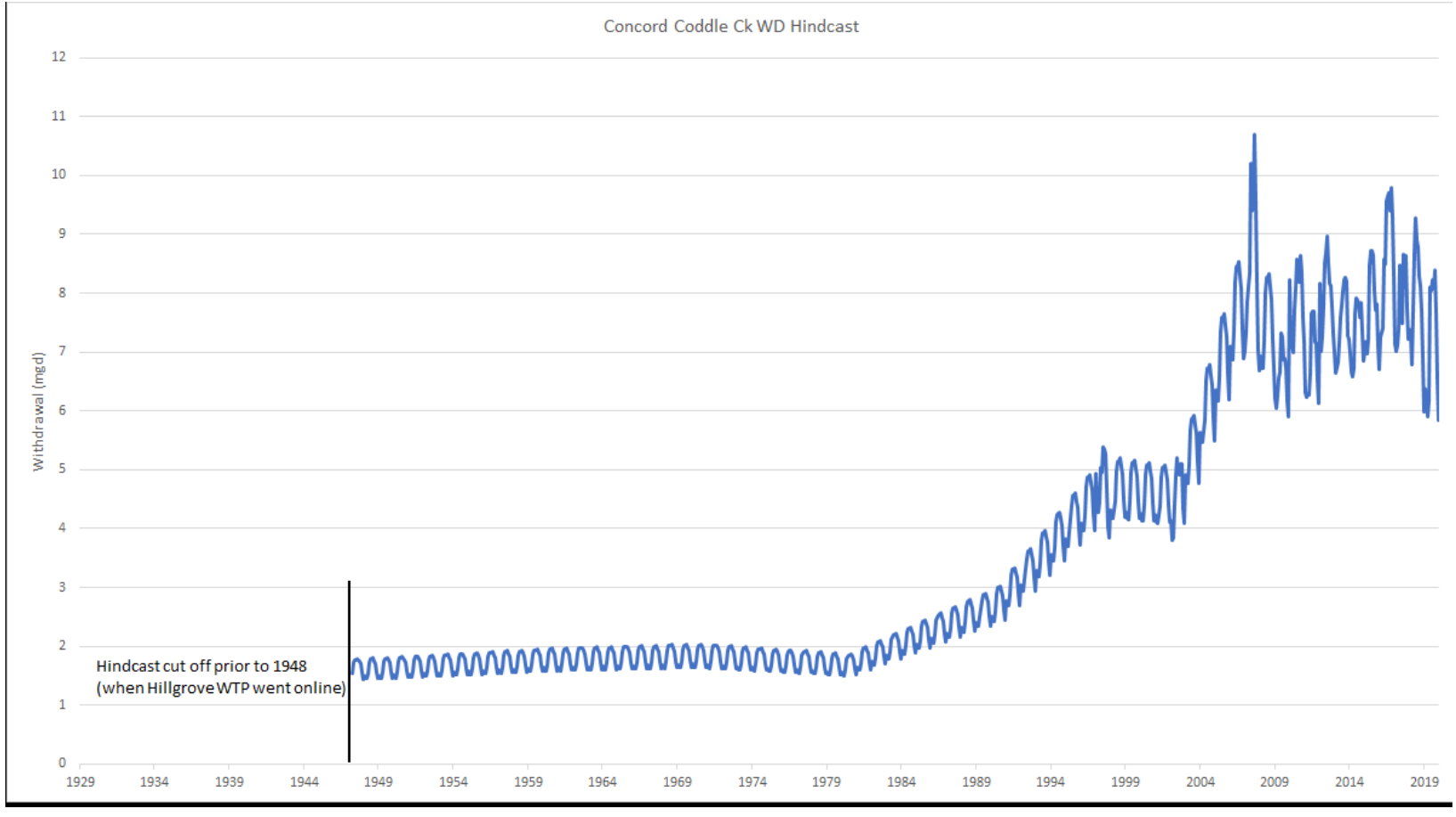
Excluded are purchasers that do not have a surface water withdrawal in the basins

- **E.g., Yadkin County which purchases water from Jonesville**

Note: for schematic inclusion, entities must have used > 0.1 mgd in the last 5 years (or are anticipated to use > 0.1 mgd in the future), or interconnections like IBTs that have not been used yet or are used only in emergency

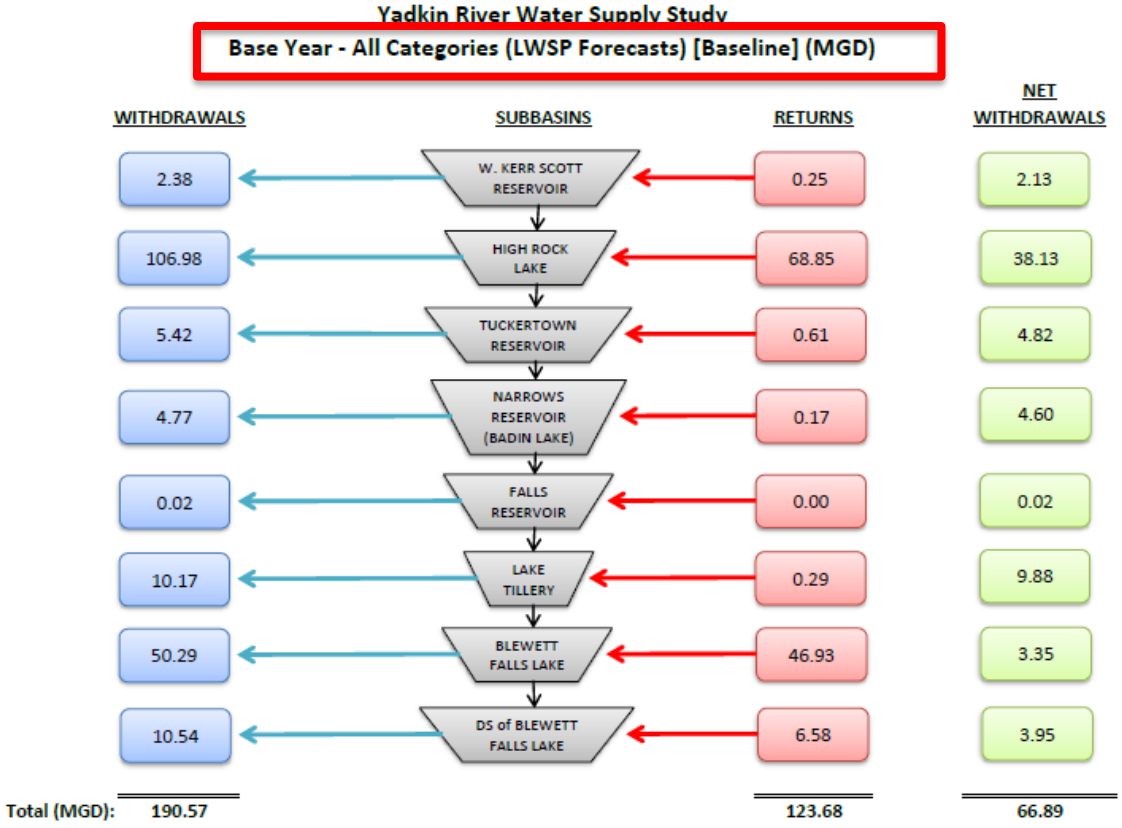
- **E.g., Charlotte (through Concord-Kannapolis), Union County (from Tillery), Greensboro (through Winston-Salem), and High Point (through Winston-Salem)**

# Hindcasting



# Sub-Basin Estimates from HDR Study

HDR Base Year = 2017
(Ag based on the highest reported water use from 5-year USGS reports available from mid-1980s to 2015)



# Breakout from HDR Study

As noted, power discharges are incorporated in the withdrawal numbers as a net withdrawal, so discharges are shown as 0.

We made the same assumption.

**Projected Withdrawals by Subbasin (mgd)**
**(LWSP Forecasts) [Baseline]**

| | Subbasin | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Total | W. KERR SCOTT RESERVOIR | HIGH ROCK LAKE | TUCKERTOWN RESERVOIR | NARROWS RESERVOIR (BADIN LAKE) | FALLS RESERVOIR | LAKE TILLERY | BLEWETT FALLS LAKE | DOWNSTREAM OF BLEWETT FALLS LAKE (NC) |
| **Public Water/Wastewater Utilities** | | | | | | | | | |
| Base | 134.35 | 0.00 | 80.48 | 4.83 | 4.51 | 0.00 | 7.84 | 32.74 | 3.96 |
| 2020 | 176.42 | 0.00 | 97.18 | 7.18 | 7.09 | 0.00 | 12.31 | 48.11 | 4.56 |
| 2030 | 195.89 | 0.00 | 105.99 | 7.37 | 7.32 | 0.00 | 20.38 | 50.04 | 4.79 |
| 2040 | 214.41 | 0.00 | 116.10 | 7.51 | 7.49 | 0.00 | 25.89 | 52.42 | 5.00 |
| 2050 | 234.03 | 0.00 | 126.24 | 7.68 | 7.70 | 0.00 | 32.05 | 55.14 | 5.23 |
| 2060 | 252.46 | 0.00 | 138.41 | 7.83 | 7.88 | 0.00 | 35.55 | 57.33 | 5.47 |
| 2070 | 274.66 | 0.00 | 148.32 | 8.32 | 8.38 | 0.00 | 39.42 | 64.60 | 5.61 |
| **Industrial** | | | | | | | | | |
| Base | 11.06 | 0.23 | 3.11 | 0.00 | 0.00 | 0.00 | 0.00 | 2.92 | 4.81 |
| 2020 | 16.56 | 0.23 | 4.11 | 0.50 | 0.50 | 0.50 | 1.00 | 3.92 | 5.81 |
| 2030 | 16.56 | 0.23 | 4.11 | 0.50 | 0.50 | 0.50 | 1.00 | 3.92 | 5.81 |
| 2040 | 16.56 | 0.23 | 4.11 | 0.50 | 0.50 | 0.50 | 1.00 | 3.92 | 5.81 |
| 2050 | 16.56 | 0.23 | 4.11 | 0.50 | 0.50 | 0.50 | 1.00 | 3.92 | 5.81 |
| 2060 | 16.56 | 0.23 | 4.11 | 0.50 | 0.50 | 0.50 | 1.00 | 3.92 | 5.81 |
| 2070 | 16.56 | 0.23 | 4.11 | 0.50 | 0.50 | 0.50 | 1.00 | 3.92 | 5.81 |
| **Agriculture/Irrigation** | | | | | | | | | |
| Base | 38.24 | 2.16 | 20.66 | 0.60 | 0.26 | 0.02 | 2.33 | 10.45 | 1.77 |
| 2020 | 54.63 | 3.94 | 29.15 | 0.88 | 0.36 | 0.02 | 3.87 | 13.94 | 2.48 |
| 2030 | 54.64 | 3.94 | 29.15 | 0.88 | 0.36 | 0.02 | 3.87 | 13.95 | 2.48 |
| 2040 | 54.66 | 3.94 | 29.15 | 0.88 | 0.36 | 0.02 | 3.87 | 13.96 | 2.48 |
| 2050 | 54.67 | 3.94 | 29.15 | 0.88 | 0.36 | 0.02 | 3.87 | 13.97 | 2.48 |
| 2060 | 54.68 | 3.94 | 29.15 | 0.88 | 0.36 | 0.02 | 3.87 | 13.99 | 2.48 |
| 2070 | 54.70 | 3.94 | 29.15 | 0.88 | 0.36 | 0.02 | 3.87 | 14.00 | 2.48 |
| **Power** | | | | | | | | | |
| Base | 6.92 | 0.00 | 2.74 | 0.00 | 0.00 | 0.00 | 0.00 | 4.18 | 0.00 |
| 2020 | 8.00 | 0.00 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 0.00 |
| 2030 | 14.00 | 0.00 | 9.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 0.00 |
| 2040 | 14.00 | 0.00 | 9.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 0.00 |
| 2050 | 6.00 | 0.00 | 6.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2060 | 42.00 | 0.00 | 42.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2070 | 42.00 | 0.00 | 42.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total** | | | | | | | | | |
| Base | 190.57 | 2.38 | 106.98 | 5.42 | 4.77 | 0.02 | 10.17 | 50.29 | 10.54 |
| 2020 | 255.61 | 4.17 | 133.44 | 8.56 | 7.95 | 0.52 | 17.17 | 70.96 | 12.85 |
| 2030 | 281.09 | 4.17 | 148.25 | 8.74 | 8.18 | 0.52 | 25.25 | 72.90 | 13.07 |
| 2040 | 299.63 | 4.17 | 158.36 | 8.89 | 8.35 | 0.52 | 30.75 | 75.29 | 13.29 |
| 2050 | 311.25 | 4.17 | 165.50 | 9.06 | 8.56 | 0.52 | 36.92 | 73.03 | 13.51 |
| 2060 | 365.70 | 4.17 | 213.67 | 9.20 | 8.74 | 0.52 | 40.41 | 75.23 | 13.76 |
| 2070 | 387.91 | 4.17 | 223.58 | 9.70 | 9.24 | 0.52 | 44.29 | 82.52 | 13.90 |

# Breakout from HDR Study

**Projected Returns by Subbasin (mgd)**
**(LWSP Forecasts) [Baseline]**

| Year | Subbasin | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | W. KERR SCOTT RESERVOIR | HIGH ROCK LAKE | TUCKERTOWN RESERVOIR | NARROWS RESERVOIR (BADIN LAKE) | FALLS RESERVOIR | LAKE TILLERY | BLEWETT FALLS LAKE | DOWNSTREAM OF BLEWETT FALLS LAKE (NC) |
| **Public Water/Wastewater Utilities** | | | | | | | | | |
| Base | 119.09 | 0.00 | 65.39 | 0.61 | 0.00 | 0.00 | 0.29 | 46.40 | 6.39 |
| 2020 | 136.89 | 0.00 | 77.86 | 0.69 | 0.00 | 0.00 | 0.30 | 51.60 | 6.44 |
| 2030 | 156.04 | 0.00 | 84.62 | 0.73 | 0.00 | 0.00 | 0.32 | 63.77 | 6.60 |
| 2040 | 180.33 | 0.00 | 92.12 | 0.77 | 0.00 | 0.00 | 4.74 | 75.93 | 6.77 |
| 2050 | 203.08 | 0.00 | 99.50 | 0.80 | 0.00 | 0.00 | 8.46 | 87.38 | 6.94 |
| 2060 | 220.42 | 0.00 | 108.49 | 0.84 | 0.00 | 0.00 | 1.84 | 102.12 | 7.12 |
| 2070 | 246.10 | 0.00 | 117.24 | 0.89 | 0.00 | 0.00 | 2.13 | 118.53 | 7.30 |
| **Industrial** | | | | | | | | | |
| Base | 4.60 | 0.25 | 3.46 | 0.00 | 0.17 | 0.00 | 0.00 | 0.53 | 0.19 |
| 2020 | 4.62 | 0.25 | 3.47 | 0.00 | 0.18 | 0.00 | 0.00 | 0.53 | 0.19 |
| 2030 | 4.69 | 0.25 | 3.49 | 0.00 | 0.23 | 0.00 | 0.00 | 0.53 | 0.19 |
| 2040 | 4.77 | 0.25 | 3.50 | 0.00 | 0.30 | 0.00 | 0.00 | 0.53 | 0.19 |
| 2050 | 4.88 | 0.25 | 3.52 | 0.00 | 0.38 | 0.00 | 0.00 | 0.53 | 0.19 |
| 2060 | 5.01 | 0.25 | 3.54 | 0.00 | 0.49 | 0.00 | 0.00 | 0.53 | 0.19 |
| 2070 | 5.17 | 0.25 | 3.57 | 0.00 | 0.63 | 0.00 | 0.00 | 0.53 | 0.19 |
| **Agriculture/Irrigation** | | | | | | | | | |
| Base | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2020 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2030 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2040 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2050 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2060 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2070 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Power** | | | | | | | | | |
| Base | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2020 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2030 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2040 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2050 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2060 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2070 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total** | | | | | | | | | |
| Base | 123.68 | 0.25 | 68.85 | 0.61 | 0.17 | 0.00 | 0.29 | 46.93 | 6.58 |
| 2020 | 141.51 | 0.25 | 81.32 | 0.69 | 0.18 | 0.00 | 0.30 | 52.13 | 6.63 |
| 2030 | 160.72 | 0.25 | 88.10 | 0.73 | 0.23 | 0.00 | 0.32 | 64.30 | 6.79 |
| 2040 | 185.10 | 0.25 | 95.63 | 0.77 | 0.30 | 0.00 | 4.74 | 76.46 | 6.96 |
| 2050 | 207.96 | 0.25 | 103.02 | 0.80 | 0.38 | 0.00 | 8.46 | 87.91 | 7.13 |
| 2060 | 225.42 | 0.25 | 112.03 | 0.84 | 0.49 | 0.00 | 1.84 | 102.65 | 7.31 |
| 2070 | 251.27 | 0.25 | 120.81 | 0.89 | 0.63 | 0.00 | 2.13 | 119.06 | 7.49 |

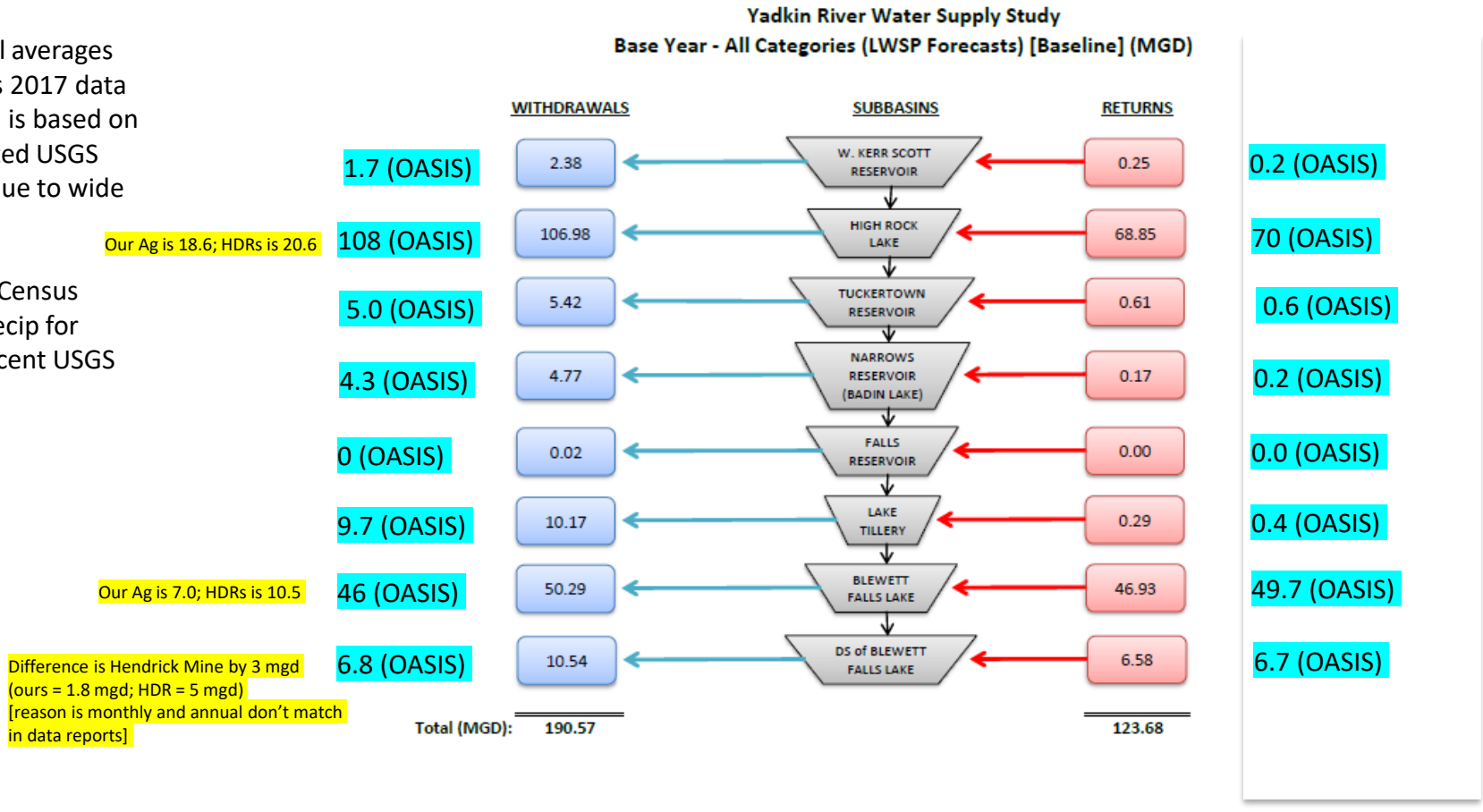
# Aggregation of Impairments

- Current conditions OASIS run (Basecase) uses 2015-2019 averages
- Compare with HDR Baseline conditions which use 2017 data

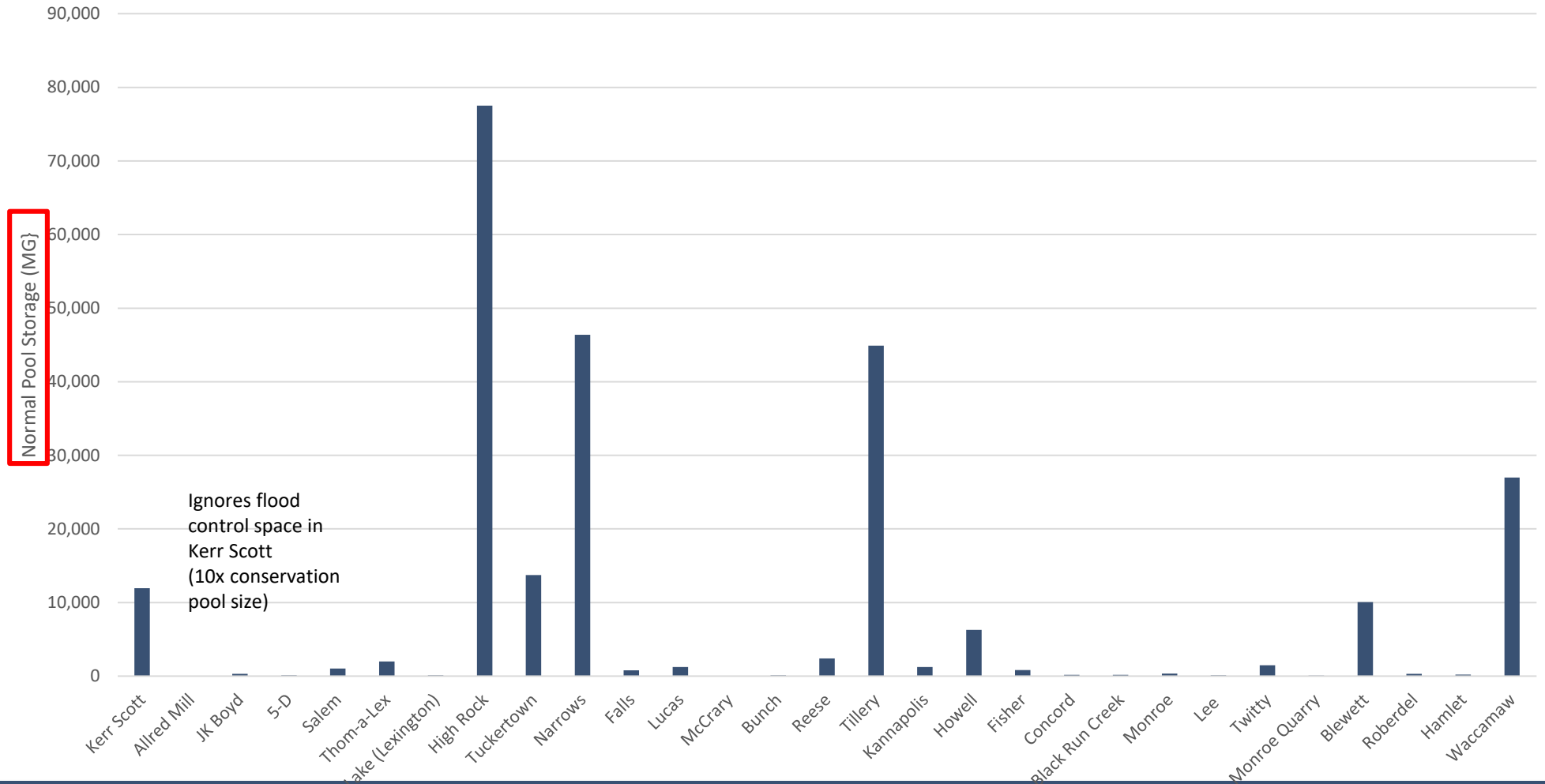
# OASIS Input Data Comparison

Uses 2015-2019 annual averages for base year, HDR uses 2017 data for all except Ag, which is based on largest of 5-year reported USGS data starting in 1990 (due to wide variation).

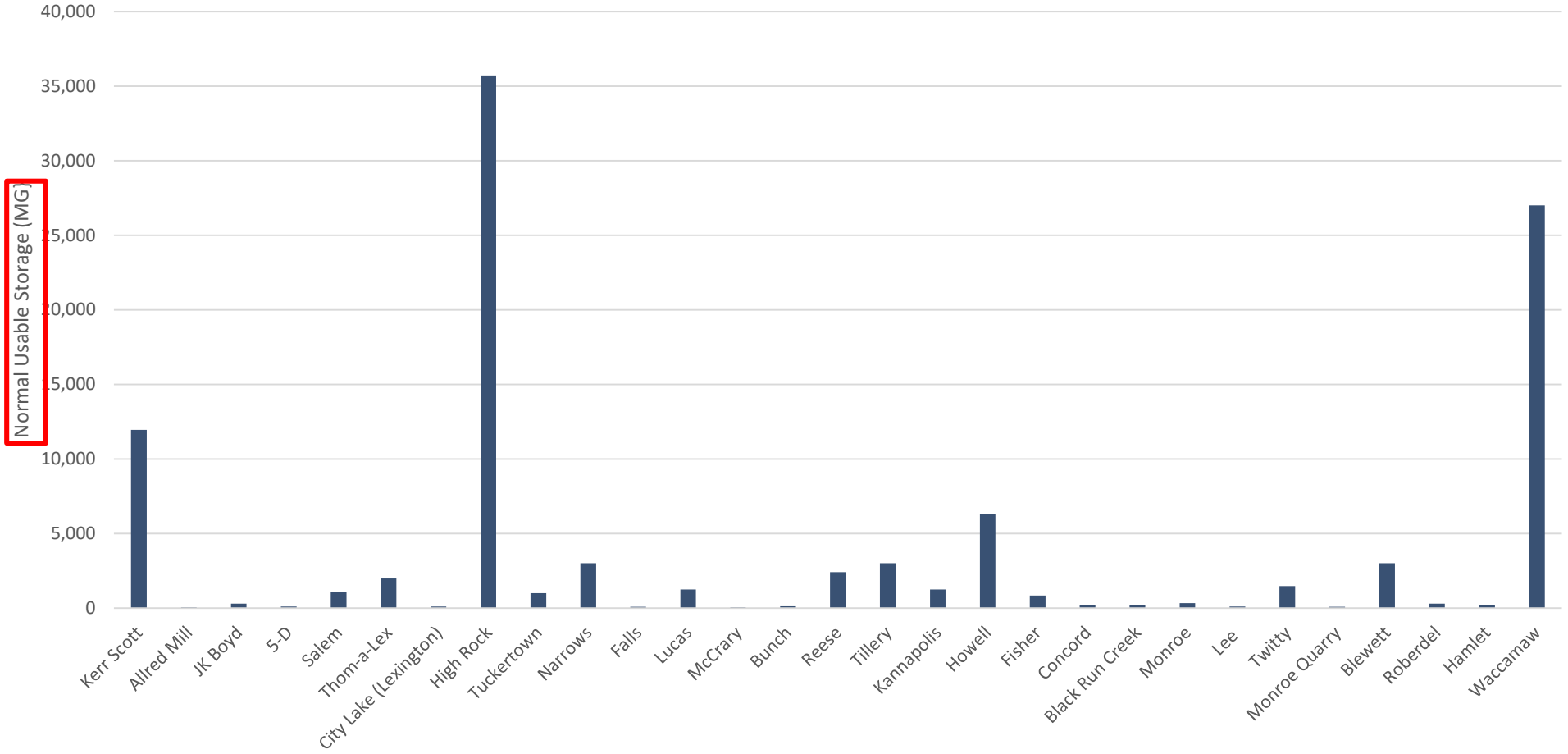
Our Ag based on 2017 Census data, run with 2015 precip for comparison to most recent USGS report.



# Reservoir Storage Summary



# Reservoir Storage Summary



# Reservoir Impairments
# (Using High Rock and Narrows as an Example)

1224. High Rock Lake at High Rock, N. C.

Location.--Lat 35°36'02", long 80°14'06", at dam on Yadkin River 0.8 mile northwest of High Rock, Davidson County, 2 miles upstream from Lick Creek, and at mile 252.3.

Drainage area.--4,000 sq mi, approximately.

Records available.--November 1927 to September 1960.

Gage.--Water-stage recorder and staff gage. Datum of gage is 30.9 ft (revised) below mean sea level, datum of 1929.

Remarks.--Lake used for hydroelectric power development was first put in operation Nov. 7, 1927. Total capacity is 11,090,000,000 cu ft and usable capacity is 10,230,000,000 cu ft between elevations 625 and 655 ft (top of gates). Figures given herein represent total contents. Records previously published as change in contents, equivalent in cubic feet per second.

Cooperation.--Records furnished by Yadkin, Inc. (formerly Carolina Aluminum Co.).

Contents, in millions of cubic feet, on last day of month

| Water year | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1928 | - | 0 | 7,932 | 4,461 | 6,914 | 8,502 | 11,025 | 11,058 | 10,960 | 9,725 | 10,928 | 11,025 |
| 1929 | 11,025 | 9,878 | 8,172 | 6,552 | 10,700 | 11,058 | 11,025 | 10,960 | 11,058 | 10,505 | 8,338 | 5,376 |
| 1930 | 10,992 | 11,058 | 11,058 | 10,895 | 10,635 | 10,765 | 8,784 | 6,412 | 10,472 | 3,195 | 3,393 | 2,330 |
| 1931 | 1,072 | 1,570 | 3,256 | 4,604 | 2,892 | 5,397 | 11,025 | 11,090 | 8,784 | 9,158 | 10,992 | 8,195 |
| 1932 | 4,543 | 2,664 | 4,291 | 11,090 | 10,321 | 10,668 | 11,025 | 10,850 | 10,159 | 5,363 | 5,439 | 3,433 |
| 1933 | 11,058 | 11,077 | 10,882 | 11,070 | 10,440 | 10,947 | 10,824 | 10,002 | 8,624 | 6,842 | 7,618 | 9,797 |
| 1934 | 2,538 | 1,327 | 1,262 | 882 | 4,696 | 10,973 | 10,921 | 11,070 | 10,315 | 11,032 | 11,077 | 11,025 |
| 1935 | 9,996 | 9,828 | 11,064 | 11,051 | 11,084 | 10,739 | 10,862 | 10,973 | 7,706 | 10,084 | 7,207 | 6,904 |
| 1936 | 3,681 | 3,237 | 1,001 | 11,058 | 10,732 | 10,992 | 11,045 | 9,048 | 9,158 | 8,426 | 9,990 | 6,142 |
| 1937 | 9,743 | 4,682 | 9,365 | 10,674 | 11,032 | 10,512 | 11,058 | 10,264 | 7,539 | 3,872 | 9,036 | 6,004 |
| 1938 | 11,058 | 9,815 | 6,250 | 5,978 | 4,155 | 5,055 | 4,025 | 4,714 | 9,042 | 11,090 | 9,158 | 4,899 |
| 1939 | 2,441 | 4,393 | 6,066 | 6,575 | 11,025 | 11,090 | 10,765 | 7,985 | 6,203 | 10,830 | 10,700 | 6,528 |
| 1940 | 2,198 | 1,268 | 2,064 | 1,244 | 3,736 | 4,155 | 6,769 | 7,828 | 8,255 | 8,200 | 10,895 | 8,420 |
| 1941 | 3,262 | 6,250 | 5,978 | 5,934 | 4,750 | 6,672 | 7,262 | 2,920 | 2,920 | 10,570 | 9,100 | 5,586 |
| 1942 | 2,318 | 1,959 | 2,581 | 2,318 | 6,473 | 10,103 | 6,720 | 10,396 | 9,014 | 6,691 | 8,956 | 7,565 |
| 1943 | 4,257 | 5,657 | 10,128 | 11,090 | 9,014 | 10,895 | 10,661 | 7,948 | 9,347 | 10,590 | 9,761 | 8,830 |
| 1944 | 7,545 | 6,514 | 4,328 | 5,594 | 11,031 | 11,051 | 10,785 | 9,653 | 6,551 | 10,128 | 6,133 | 10,875 |
| 1945 | 10,538 | 9,569 | 9,112 | 9,106 | 11,032 | 9,996 | 10,271 | 9,112 | 5,363 | 9,467 | 6,394 | 11,090 |
| 1946 | 9,002 | 7,770 | 10,999 | 10,752 | 10,824 | 10,960 | 9,671 | 10,642 | 6,188 | 3,878 | 5,384 | 3,745 |
| 1947 | 3,240 | 2,755 | 2,174 | 10,765 | 6,528 | 6,624 | 8,255 | 7,775 | 10,505 | 6,672 | 4,532 | 6,909 |
| 1948 | 11,005 | 11,051 | 8,646 | 8,646 | 10,817 | 11,058 | 9,872 | 10,538 | 8,530 | 6,315 | 8,698 | 4,485 |
| 1949 | 3,454 | 11,025 | 11,058 | 9,878 | 10,960 | 11,050 | 10,960 | 9,635 | 9,455 | 10,700 | 11,205 | 10,378 |
| 1950 | 10,960 | 10,960 | 8,640 | 8,870 | 9,275 | 10,830 | 9,575 | 10,960 | 8,530 | 9,187 | 9,755 | 8,200 |
| 1951 | 6,624 | 5,418 | 8,812 | 6,914 | 7,722 | 8,755 | 10,895 | 9,455 | 10,065 | 10,570 | 9,100 | 9,575 |
| 1952 | 8,255 | 7,932 | 10,378 | 9,335 | 9,515 | 11,090 | 11,025 | 9,455 | 9,575 | 9,215 | 10,700 | 9,042 |
| 1953 | 8,348 | 10,340 | 9,695 | 10,700 | 10,960 | 11,025 | 9,455 | 10,190 | 10,609 | 9,215 | 9,455 | 10,002 |
| 1954 | 10,002 | 9,515 | 8,090 | 10,505 | 10,065 | 10,190 | 8,420 | 8,985 | 8,640 | 6,250 | 7,880 | 5,376 |
| 1955 | 5,934 | 4,189 | 6,066 | 4,393 | 7,414 | 6,624 | 10,427 | 8,148 | 6,110 | 5,376 | 5,211 | 4,899 |
| 1956 | 4,058 | 2,568 | 1,638 | 823 | 3,672 | 5,016 | 9,456 | 8,364 | 5,890 | 5,016 | 2,441 | 10,001 |
| 1957 | 8,364 | 5,172 | 6,963 | 3,424 | 11,018 | 10,554 | 10,619 | 8,869 | 10,879 | 9,759 | 7,161 | 10,879 |
| 1958 | 9,396 | 11,018 | 10,619 | 11,018 | 11,018 | 11,018 | 11,090 | 10,490 | 10,182 | 9,215 | 9,336 | 3,928 |
| 1959 | 2,492 | 2,492 | 9,819 | 10,947 | 9,456 | 8,700 | 10,813 | 8,813 | 8,644 | 10,365 | 10,748 | 9,819 |
| 1960 | 10,813 | 9,336 | 10,947 | 10,619 | 11,018 | 11,018 | 11,018 | 10,947 | 10,061 | 9,275 | 9,096 | 5,978 |



1228.44. Badin Lake near Badin, N. C.

Location.--Lat 35°25'10", long 80°05'34" (revised), at dam on Yadkin River, 1½ miles northeast of Badin, Stanly County, 2½ miles upstream from Falls Dam, 4 miles upstream from Uwharrie River, and at mile 236.

Drainage area.--4,180 sq mi, approximately.

Records available.--December 1917 to September 1960.

Gage.--Water-stage recorder and staff gage. Datum of gage is 30.9 ft (revised) below mean sea level, datum of 1929.

Remarks.--Badin Lake (locally known as Narrows Reservoir) used for hydroelectric power development, was first put in operation July 12, 1917 (revised). Total capacity is 10,497,960,000 cu ft and usable capacity is 6,202,584,000 cu ft between elevations 505.0 and 541.1 ft (revised). Figures given herein represent total contents. Records not previously published; changes in contents, equivalent in cubic feet per second, for a group of reservoirs including this one have been published since March 1928.

Cooperation.--Records furnished by Yadkin, Inc. (formerly Carolina Aluminum Co.).

Contents, in millions of cubic feet, on last day of month

| Water year | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1917 | - | - | - | - | - | - | - | - | - | - | - | - |
| 1918 | - | - | 6,540 | 9,961 | 8,927 | 9,260 | 9,954 | 9,897 | 8,685 | 8,575 | 10,288 | 10,012 |
| 1919 | 10,524 | 10,430 | 10,442 | 10,394 | 10,254 | 10,024 | 10,406 | 10,453 | 10,453 | 10,453 | 10,173 | 8,916 |
| 1920 | 9,282 | 9,114 | 10,300 | 10,500 | 10,500 | 10,500 | 10,488 | 10,442 | 10,395 | 10,000 | 10,524 | 10,512 |
| 1921 | 8,639 | 10,524 | 10,500 | 10,512 | 10,500 | 10,512 | 10,500 | 10,512 | 10,418 | 10,035 | 8,411 | 8,067 |
| 1922 | 7,064 | 10,500 | 9,462 | 10,488 | 10,524 | 10,476 | 10,524 | 10,524 | 10,524 | 10,382 | 10,104 | 8,250 |
| 1923 | 7,790 | 5,058 | 8,217 | 8,685 | 9,418 | 10,382 | 10,196 | 10,453 | 7,510 | 6,274 | 9,114 | 8,751 |
| 1924 | 4,927 | 4,420 | 7,906 | 9,748 | 10,162 | 10,070 | 10,336 | 10,406 | 9,702 | 10,196 | 9,770 | 10,536 |
| 1925 | 8,938 | 6,000 | 9,805 | 10,219 | 9,530 | 8,444 | 5,700 | 6,898 | 5,359 | 5,172 | 4,847 | 5,763 |
| 1926 | 6,502 | 7,906 | 6,179 | 9,770 | 10,524 | 8,379 | 7,690 | 5,551 | 5,790 | 10,464 | 9,282 | 6,713 |
| 1927 | 5,508 | 8,358 | 10,512 | 6,530 | 10,512 | 9,759 | 7,540 | 6,782 | 9,552 | 10,092 | 10,418 | 8,520 |
| 1928 | 9,305 | 5,817 | 8,729 | 9,181 | 9,748 | 9,805 | 10,464 | 10,476 | 10,394 | 10,196 | 10,442 | 10,453 |
| 1929 | 10,524 | 10,488 | 10,230 | 10,242 | 10,302 | 10,476 | 10,442 | 10,418 | 10,453 | 10,336 | 10,286 | 10,370 |
| 1930 | 10,348 | 10,512 | 10,524 | 10,524 | 10,286 | 10,310 | 10,267 | 10,219 | 10,208 | 8,817 | 6,629 | 4,670 |
| 1931 | 4,157 | 6,150 | 8,529 | 9,964 | 9,987 | 10,030 | 10,488 | 10,524 | 9,896 | 10,067 | 10,524 | 10,056 |
| 1932 | 10,083 | 8,383 | 9,950 | 10,512 | 10,138 | 10,276 | 10,324 | 9,862 | 10,247 | 10,106 | 10,270 | 10,042 |
| 1933 | 10,377 | 10,446 | 10,382 | 10,425 | 10,430 | 10,120 | 10,129 | 10,288 | 10,219 | 9,837 | 9,987 | 10,162 |
| 1934 | 7,919 | 6,422 | 4,959 | 5,161 | 5,175 | 10,418 | 10,462 | 10,460 | 10,411 | 10,519 | 10,476 | 10,495 |
| 1935 | 9,911 | 9,768 | 10,481 | 10,476 | 10,505 | 10,364 | 10,413 | 10,329 | 10,040 | 9,959 | 9,954 | 9,856 |
| 1936 | 9,365 | 9,242 | 6,762 | 10,354 | 10,366 | 10,359 | 10,502 | 10,012 | 9,789 | 10,143 | 9,860 | 10,010 |
| 1937 | 10,111 | 9,904 | 9,794 | 10,317 | 10,359 | 10,359 | 10,444 | 10,134 | 10,189 | 10,171 | 10,010 | 10,037 |
| 1938 | 10,423 | 9,890 | 9,973 | 9,911 | 9,888 | 9,968 | 9,908 | 9,722 | 9,879 | 10,522 | 10,125 | 10,221 |
| 1939 | 7,970 | 9,810 | 9,968 | 9,902 | 10,453 | 10,515 | 10,251 | 10,155 | 10,173 | 10,138 | 10,180 | 8,232 |
| 1940 | 7,234 | 6,082 | 6,293 | 6,255 | 7,644 | 8,465 | 8,398 | 8,564 | 8,883 | 8,764 | 10,228 | 8,685 |
| 1941 | 8,597 | 8,687 | 8,540 | 9,033 | 8,678 | 9,431 | 9,936 | 9,619 | 5,984 | 10,155 | 9,927 | 10,049 |
| 1942 | 8,192 | 6,850 | 7,898 | 7,922 | 10,141 | 10,097 | 10,081 | 10,314 | 10,030 | 9,991 | 10,058 | 11,136 |
| 1943 | 9,881 | 7,710 | 10,302 | 10,519 | 10,331 | 10,491 | 10,519 | 10,274 | 10,063 | 10,120 | 10,023 | 10,182 |
| 1944 | 10,072 | 10,099 | 9,929 | 10,017 | 10,524 | 10,512 | 10,502 | 10,210 | 9,827 | 9,880 | 10,086 | 10,270 |
| 1945 | 10,256 | 10,267 | 10,242 | 10,208 | 10,519 | 10,136 | 9,879 | 10,095 | 10,097 | 10,005 | 10,290 | 10,442 |
| 1946 | 10,145 | 10,127 | 10,500 | 10,270 | 10,104 | 10,359 | 10,490 | 10,354 | 10,371 | 10,019 | 9,876 | 9,869 |
| 1947 | 8,905 | 9,305 | 7,360 | 10,359 | 10,058 | 10,127 | 9,989 | 9,966 | 9,759 | 10,127 | 9,989 | 9,950 |
| 1948 | 10,514 | 10,437 | 10,203 | 10,307 | 10,435 | 10,469 | 10,361 | 10,240 | 10,065 | 10,074 | 10,113 | 10,085 |
| 1949 | 10,056 | 10,382 | 10,476 | 10,359 | 10,312 | 10,406 | 10,336 | 10,288 | 10,382 | 10,173 | 10,476 | 10,196 |
| 1950 | 10,406 | 10,500 | 10,173 | 10,104 | 10,150 | 10,336 | 9,920 | 10,524 | 10,265 | 9,961 | 10,012 | 10,219 |
| 1951 | 9,621 | 8,314 | 10,196 | 9,989 | 10,453 | 10,104 | 10,430 | 9,372 | 10,242 | 9,966 | 9,920 | 9,350 |
| 1952 | 8,949 | 10,173 | 10,312 | 10,035 | 9,440 | 10,476 | 10,524 | 10,035 | 9,395 | 9,619 | 10,242 | 9,989 |
| 1953 | 8,722 | 7,838 | 10,081 | 10,035 | 10,312 | 10,348 | 9,821 | 9,759 | 9,816 | 9,687 | 9,305 | 9,897 |
| 1954 | 9,598 | 9,328 | 9,805 | 10,382 | 10,012 | 10,453 | 10,453 | 10,336 | 9,943 | 9,966 | 8,707 | a9,937 |
| 1955 | 10,381 | 10,264 | 10,054 | 9,914 | 10,031 | 10,007 | 10,264 | 10,054 | 9,574 | 10,124 | 10,170 | 9,799 |
| 1956 | 10,007 | 8,855 | 6,812 | 6,050 | 10,194 | 10,194 | 10,287 | 9,891 | 9,844 | 10,054 | 9,137 | 10,124 |
| 1957 | 9,914 | 10,147 | 10,147 | 9,029 | 10,427 | 10,241 | 10,357 | 10,007 | 10,474 | 10,241 | 10,241 | 10,287 |
| 1958 | 10,241 | 10,474 | 10,334 | 10,474 | 10,427 | 10,404 | 10,498 | 10,474 | 10,194 | 10,077 | 10,194 | 10,007 |
| 1959 | 9,008 | 7,825 | 7,245 | 10,381 | 10,171 | 10,311 | 10,287 | 10,194 | 10,031 | 10,381 | 10,241 | 10,194 |
| 1960 | 10,311 | 10,101 | 10,287 | 10,381 | 10,474 | 10,474 | 10,498 | 10,451 | 9,937 | 10,077 | 9,867 | 10,217 |

a Contents by capacity table used beginning Sept. 1, 1954; contents Sept. 30, 1954, by capacity table used prior to Sept. 1, 1954, was 9,966 million cubic feet.

Historic net evaporation = historic surface area (converted from storage-area curve) x estimated net evap

# Reservoir Impairment (using WSACC as an Example)

**CODDLE CREEK RESERVOIR/LAKE HOWELL WATER LEVEL REPORT**

| DATE | WATER LEVEL | RAINFALL (inches) | LAST YEAR'S WATER LEVEL | MINIMUM RELEASE DISCHARGE | | | | CODDLE CREEK INFLOW | | ESTIMATED LAKE HOWELL INFLOW | | DROUGHT STAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Discharge Over Spillway | Minimum Release Discharge | cfs | mgd | cfs | mgd | cfs | mgd | |
| 8-3-20 | 650.0 | 0 | 649.3 | No | Yes | 3* | 1.95 | 11.90 | 7.74 | 17.49 | 11.37 | Stage 1 |
| 8-10-20 | 649.9 | 0 | 649.1 | No | Yes | 3* | 1.95 | 7.75 | 5.04 | 11.39 | 7.41 | Stage 1 |
| 8-11-20 | 649.9 | 0 | 649.1 | No | Yes | 3* | 1.95 | 7.75 | 5.04 | 11.39 | 7.41 | Stage 1 |
| 8-17-20 | 650.1 | 2.1 | 648.9 | Yes | Yes | 3* | 1.95 | 12.70 | 8.26 | 18.67 | 12.13 | Stage 1 |
| 8-18-20 | 650.2 | 0 | 648.9 | Yes | Yes | 3* | 1.95 | 12.70 | 8.26 | 18.67 | 12.13 | Stage 1 |
| 8-19-20 | 650.0 | 0 | 648.9 | Yes | Yes | 3* | 1.95 | 15.50 | 10.08 | 22.79 | 14.81 | Stage 1 |
| 8-21-20 | 650.0 | 0 | 649.0 | Yes | Yes | 3* | 1.95 | 15.50 | 10.08 | 22.79 | 14.81 | Stage 1 |
| 8-24-20 | 650.1 | 0.5 | 648.9 | Yes | Yes | 3* | 1.95 | 9.90 | 6.42 | 14.51 | 9.43 | Stage 1 |
| 8-27-20 | 650.0 | 0 | 648.9 | No | Yes | 3* | 1.95 | 8.77 | 5.70 | 12.89 | 8.38 | Stage 1 |
| 8-31-20 | 650.2 | 2.0 | 648.9 | Yes | Yes | 3* | 1.95 | 262.00 | 170.30 | 385.14 | 250.34 | Stage 1 |
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Full Pond Level – 650.0'

DROUGHT OPERATING CURVES:

Normal: > 70% usable volume (645.5 feet), > 75% historical inflow, minimum release = 6 cfs.
Stage 1: > 70% usable volume (645.5 feet), < 75% historical inflow, minimum release = 3 cfs.
Stage 2: 70% usable volume (645 feet), minimum release = 2 cfs.
Stage 3: 60% to 40% usable volume (643.9 feet to 640.4 feet), (depending upon the month), minimum release = 2 cfs.
Stage 4: 50% to 30% usable volume (642.2 feet to 638.4 feet), (depending upon the month), minimum release = 2 cfs.

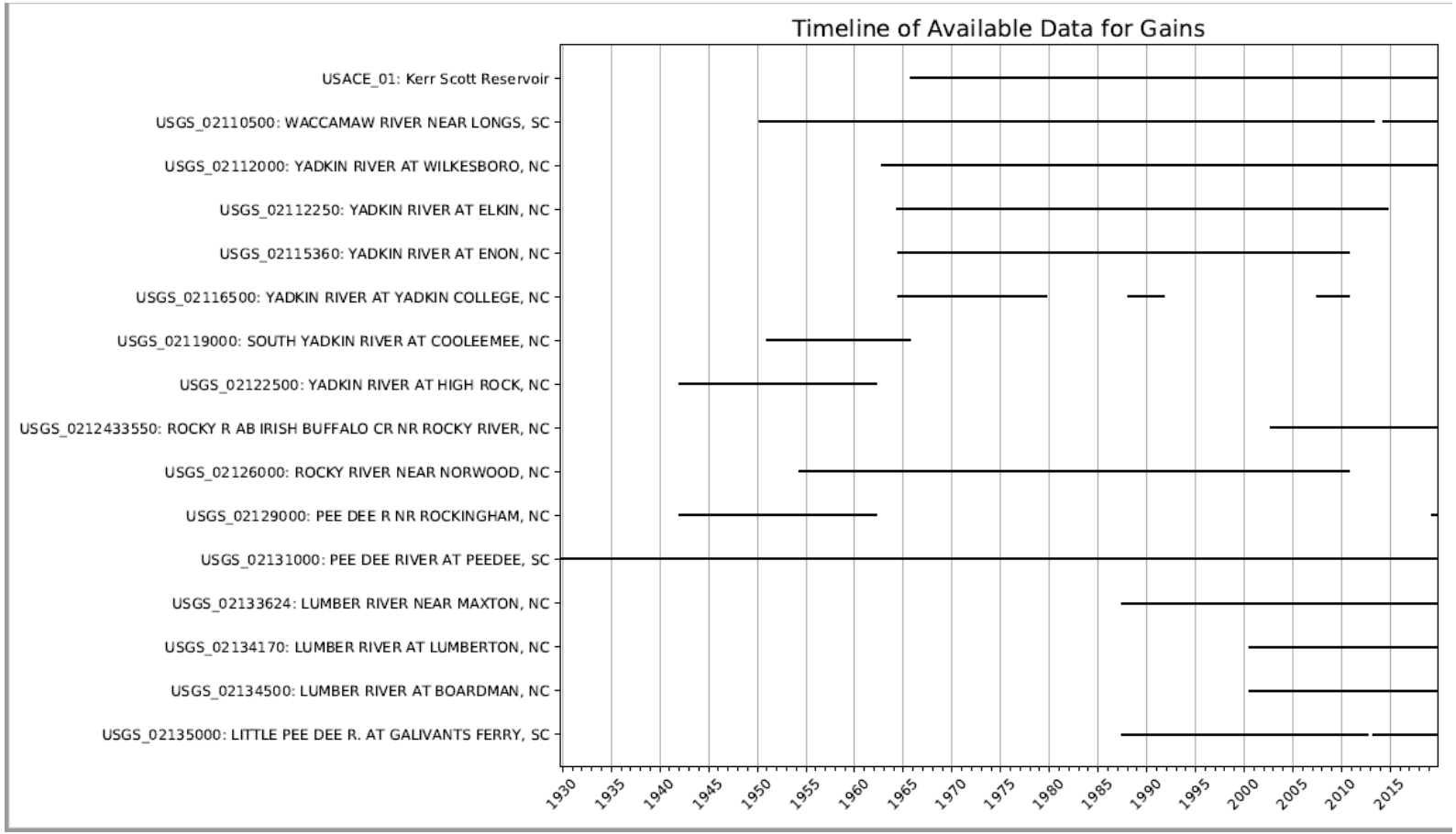
*The minimum release discharge is a total of 2.0 cfs – 1.0 cfs from Coddle Creek Reservoir/Lake Howell and 1.0 cfs from Coddle Creek Water Treatment Plant.

# Unimpairment of Gages

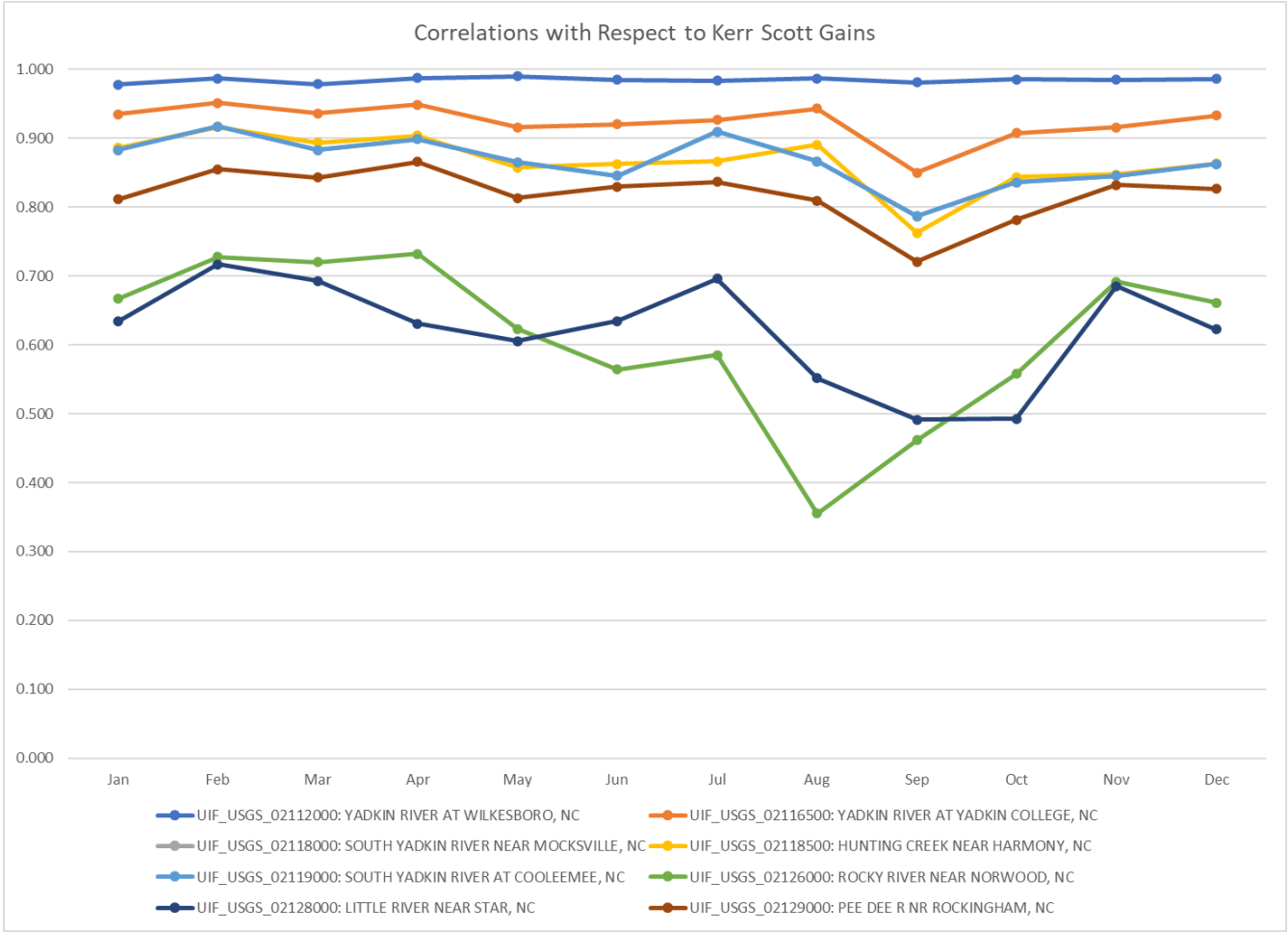
All flows in cfs

| Date | Observed Flow<br>Yadkin River at Yadkin College, NC<br>02116500 | Discharge<br>Yadkinville WWTP<br>NC0020338 | Discharge<br>Davie Co Sparks Rd WTP<br>NC0084212 | Discharge<br>Bermuda Run WWTP<br>NC0055158 | Discharge<br>Davidson Water WTP<br>NC0084425 | Discharge<br>Winston Salem Archie E WWTP<br>NC0037834 | Discharge<br>Davidson Water WTP<br>NC0084425 | Withdrawals<br>Yadkinville<br>02-99-015 | Withdrawals<br>Davie Co Sparks Rd WD<br>02-30-015 | Withdrawals<br>WS Idols Dam WD<br>02-34-010<br>02-34-010 | Withdrawals<br>Davidson Water<br>02-29-025 | Reservoir Impairment<br>5-D Reservoir<br>change in storage | Reservoir Impairment<br>5-D Reservoir<br>net evap | Total<br>Impairment<br>in this reach | Total impairment<br>above upstream<br>gage | Total<br>impairment<br>to downstream gage | Total<br>Unimpaire<br>Flow<br>02116500<br>USGS_02116 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12/18/1996 | 3230 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 19.6 | 51.4 | 3281 |
| 12/19/1996 | 3540 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 45.5 | 77.2 | 3617 |
| 12/20/1996 | 3830 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | -323.6 | -291.8 | 3538 |
| 12/21/1996 | 3350 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 53.5 | 85.2 | 3435 |
| 12/22/1996 | 3070 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 254.2 | 285.9 | 3356 |
| 12/23/1996 | 2880 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 128.2 | 159.9 | 3040 |
| 12/24/1996 | 2860 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | -24.6 | 7.2 | 2867 |
| 12/25/1996 | 3230 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | -356.2 | -324.5 | 2906 |
| 12/26/1996 | 3240 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 3.1 | 34.8 | 3275 |
| 12/27/1996 | 3000 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 251.7 | 283.4 | 3283 |
| 12/28/1996 | 2810 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | -49.8 | -18.0 | 2792 |
| 12/29/1996 | 2780 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | -59.7 | -28.0 | 2752 |
| 12/30/1996 | 2860 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | 51.0 | 82.8 | 2943 |
| 12/31/1996 | 2730 | 1.27 | 0.29 | 0.20 | 0.31 | 32.18 | 0.31 | 1.40 | 1.48 | 51.17 | 12.26 | | | 31.7 | -51.0 | -19.3 | 2711 |
| 1/1/1997 | 2680 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | -417.7 | -382.3 | 2298 |
| 1/2/1997 | 2680 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | 331.2 | 366.6 | 3047 |
| 1/3/1997 | 2660 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | 9.0 | 44.4 | 2704 |
| 1/4/1997 | 2620 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | 10.3 | 45.7 | 2666 |
| 1/5/1997 | 2650 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | -27.0 | 8.4 | 2658 |
| 1/6/1997 | 3140 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | -122.2 | -86.8 | 3053 |
| 1/7/1997 | 3020 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | 34.2 | 69.6 | 3090 |
| 1/8/1997 | 2720 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | 35.5 | 70.9 | 2791 |
| 1/9/1997 | 3460 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | 387.6 | 423.0 | 3883 |
| 1/10/1997 | 4940 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | -159.5 | -124.0 | 4816 |
| 1/11/1997 | 4470 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | -32.4 | 3.0 | 4473 |
| 1/12/1997 | 3710 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | -140.0 | -104.6 | 3605 |
| 1/13/1997 | 3230 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | 10.3 | 45.7 | 3276 |
| 1/14/1997 | 2940 | 1.19 | 0.28 | 0.19 | 0.31 | 33.06 | 0.31 | 1.61 | 1.56 | 54.97 | 12.61 | | | 35.4 | -14.9 | 20.5 | 2960 |

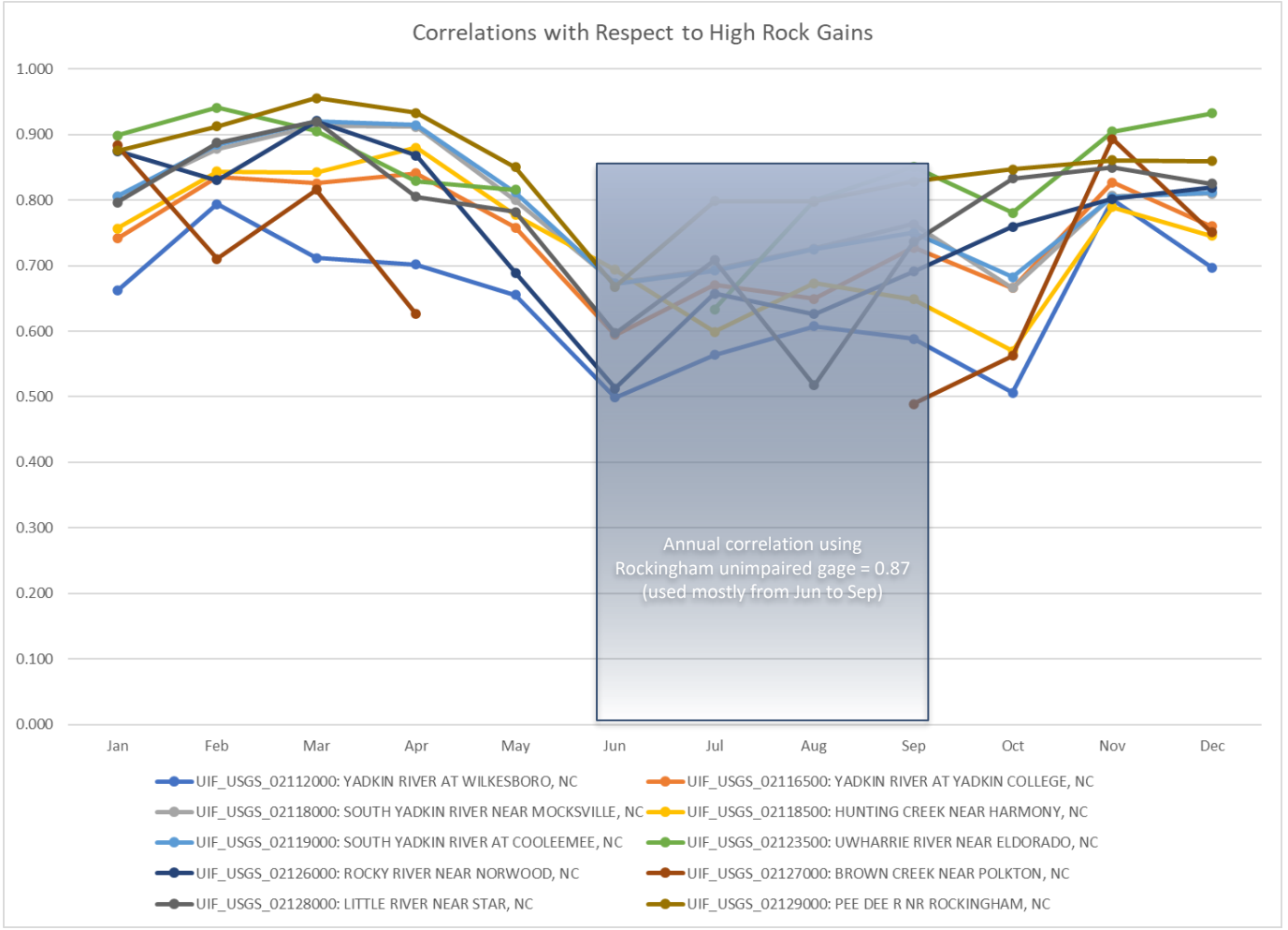
# Fill In Missing Record



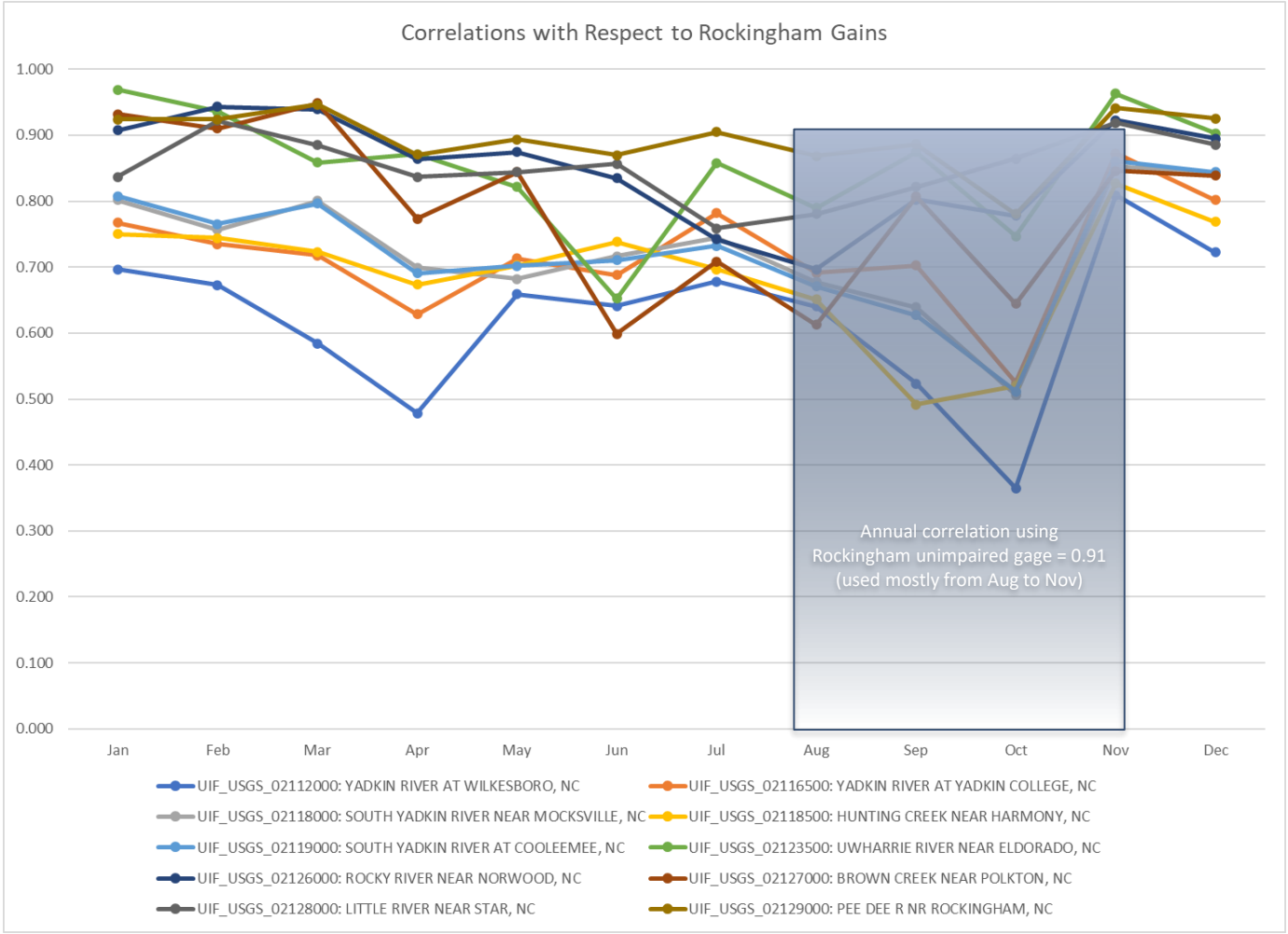
# Correlation



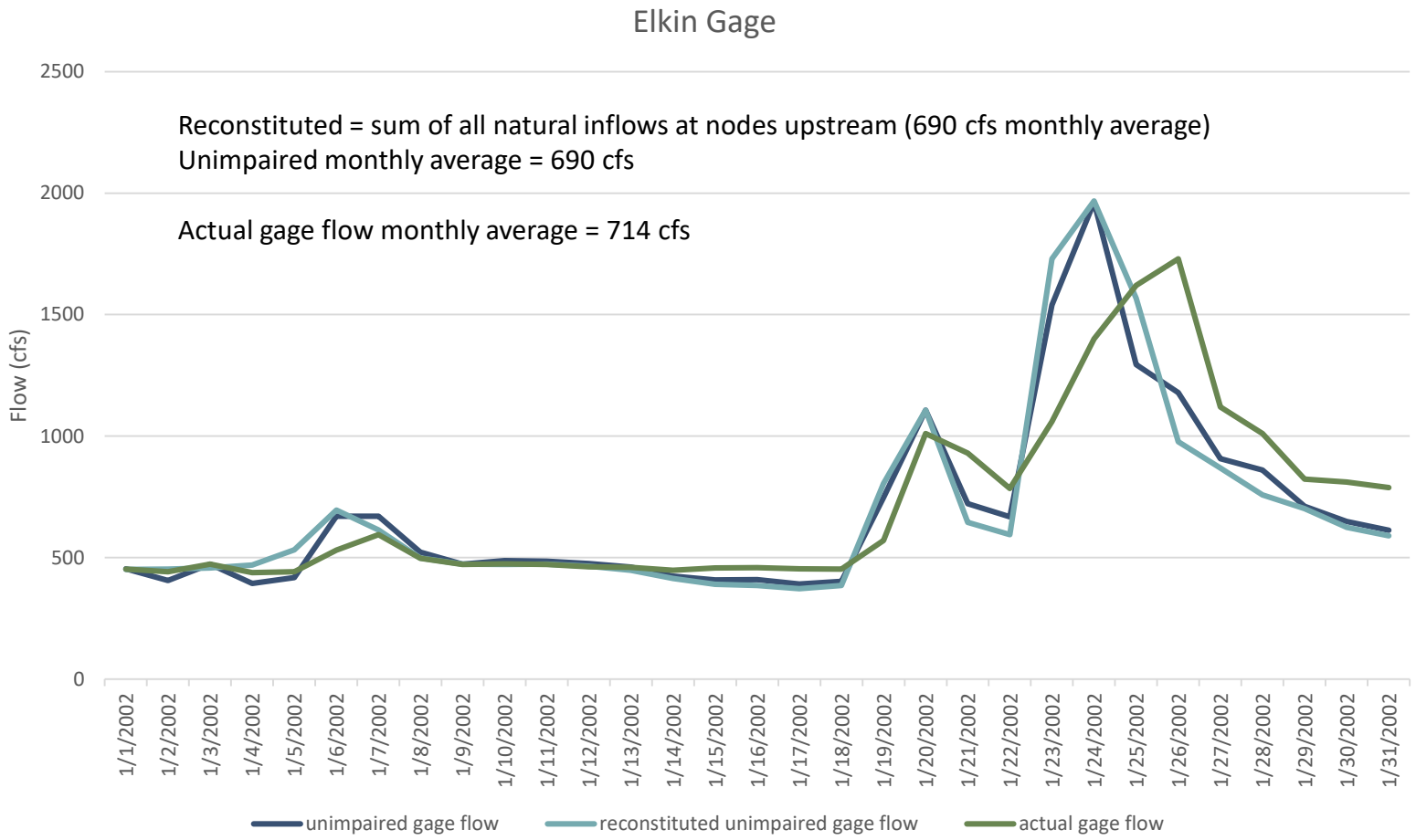
# Correlation



# Correlation



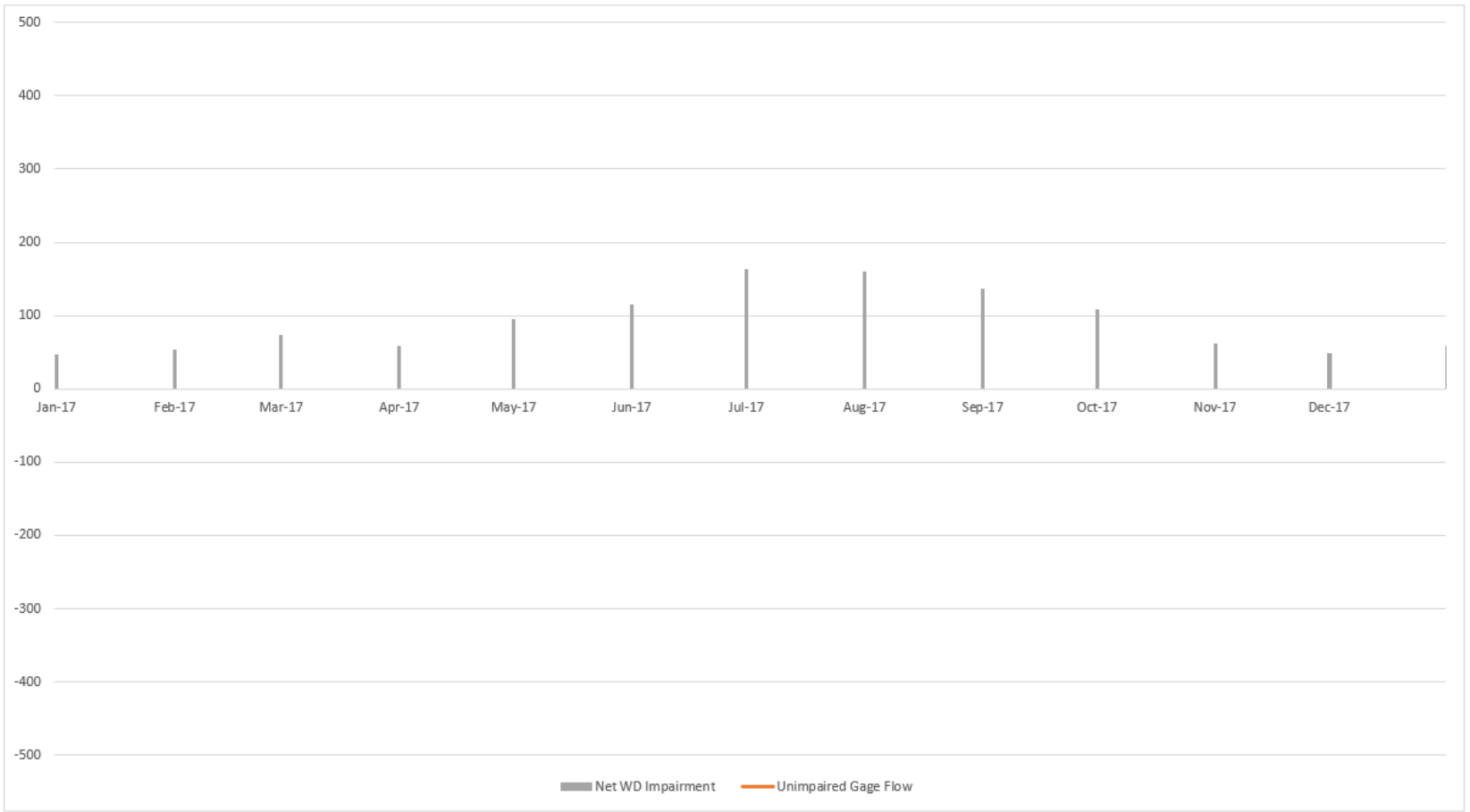
# Finalize to Daily Timestep



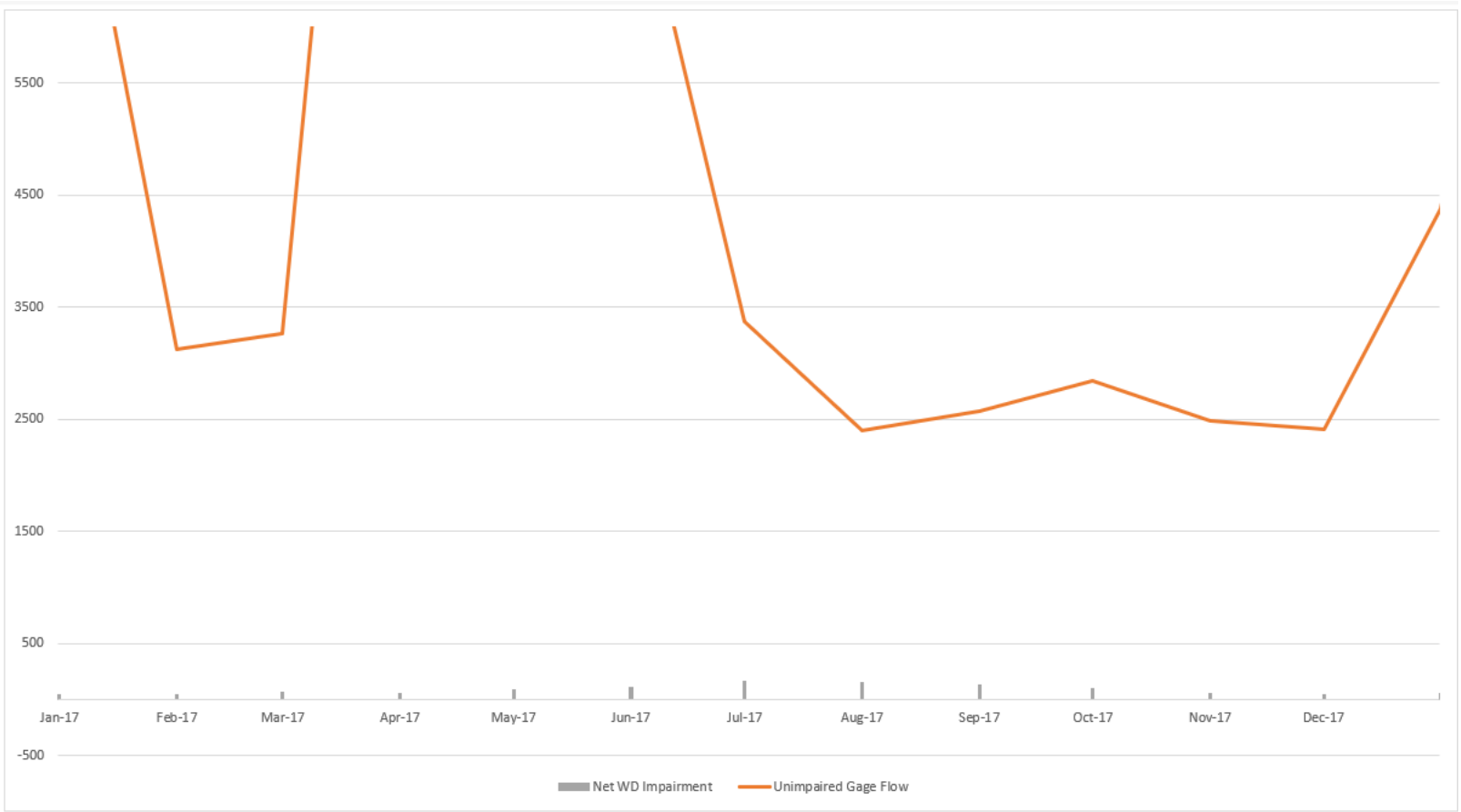
# Impairment Summary

| | | | | |
|---|---|---|---|---|
| | Summary of Impairments Upstream of Key Gages or Locations (excluding reservoir operations) | | | |
| | 2017 Data | | | |
| | | Net Impairment (cfs) | Remarks | |
| | Wilkesboro | 13.6 | About 11.5 for M&I, rest for Ag (about 2.5) assigned to Kerr Scott | |
| In other words, | Elkin | 9.4 | Mostly from WW return between Wilkesboro and Elkin | |
| net impairment | Enon | 30.3 | Mostly W-S withdrawal (about 20 cfs from Swanns intake) | |
| drops by about 4 cfs | Yadkin College | 34 | Breakout of major uses is as follows: | * for inflow unimpairment, when factoring in reservoir operations, includes routed change in storage at Kerr Scott (avg impa |
| from Wilkesboro | | | W-S withdrawal of 37 cfs from Idols intake | |
| to Elkin | | | W-S WW return of 49 cfs (23 cfs to muddy creek, 26 cfs to salem archie) | |
| | | | Davidson withdrawal of 15.4 cfs (no WW return) | |
| | | | | So using these numbers, YC impairment = Enon gage + W-S WD - WW discharge in reach = 30.3 + 37 + 15.4 - 49 = 33.7 |
| | | | | Actual impairment of 34 cfs reflects other WDs and WW discharges |
| | | | | Ag allocated to Kerr Scott propagated downstream, but additional Ag only shown again for High Rock |
| | High Rock | 63.8 | 24.9 net impairment in this reach, mostly from Ag (28.8) in HR subbasin allocated to this location | |
| | | | So total net impairment = 34 (at Yadkin College) + 24.9 in this reach = 63.8 | |
| | Rockingham | 93.8 | 7.5 cfs WD for Asheboro down to Tillery (no WW return) | |
| | | | 14.8 cfs WW return for Rocky River Mallard Creek (from Charlotte, so no WD) | |
| | | | 6.5 cfs WW return for Rocky River Mooresville (from outside basin, so no WD) | |
| | | | 10 cfs WW return to WSACC (from outside basin, so no WD) | |
| | | | 17 cfs Ag WD for subbasins TT, Na, Fa, Till, and Blew | |
| | | | **10 cfs WD for Anson County (WW returned DS)** | |
| | | | **6.5 cfs WD for Smith plant** | |
| | | | **4 cfs WD for Montgomery County (no WW return back in)** | |
| | | | **5.7 cfs WD for Richmond County (no WW return back in)** | |
| | | | **4.1 cfs WD for Hedrick Mine** | |
| | | | Net = 55 WD - 30 WW = 25 WD in this reach | |
| | | | So HR + Rockingham = 63.8 + 25 = 88.8 cfs | |
| | | | Actual in unimpairment spreadsheet = 93.8 cfs, so close | |
| | | | To Blewett, total net impairment would 93.8 - WDs in bold (or about 33 cfs), or 60 cfs | |
| | | | So change in impairment from High Rock to Rockingham is small (obviously not including reservoir operations) | |
| | | | Provisional inflows remove effect of reservoir operations by using either gains downstream of reservoirs | |
| | | | or gages on tributaries that are drainage area adjusted | |

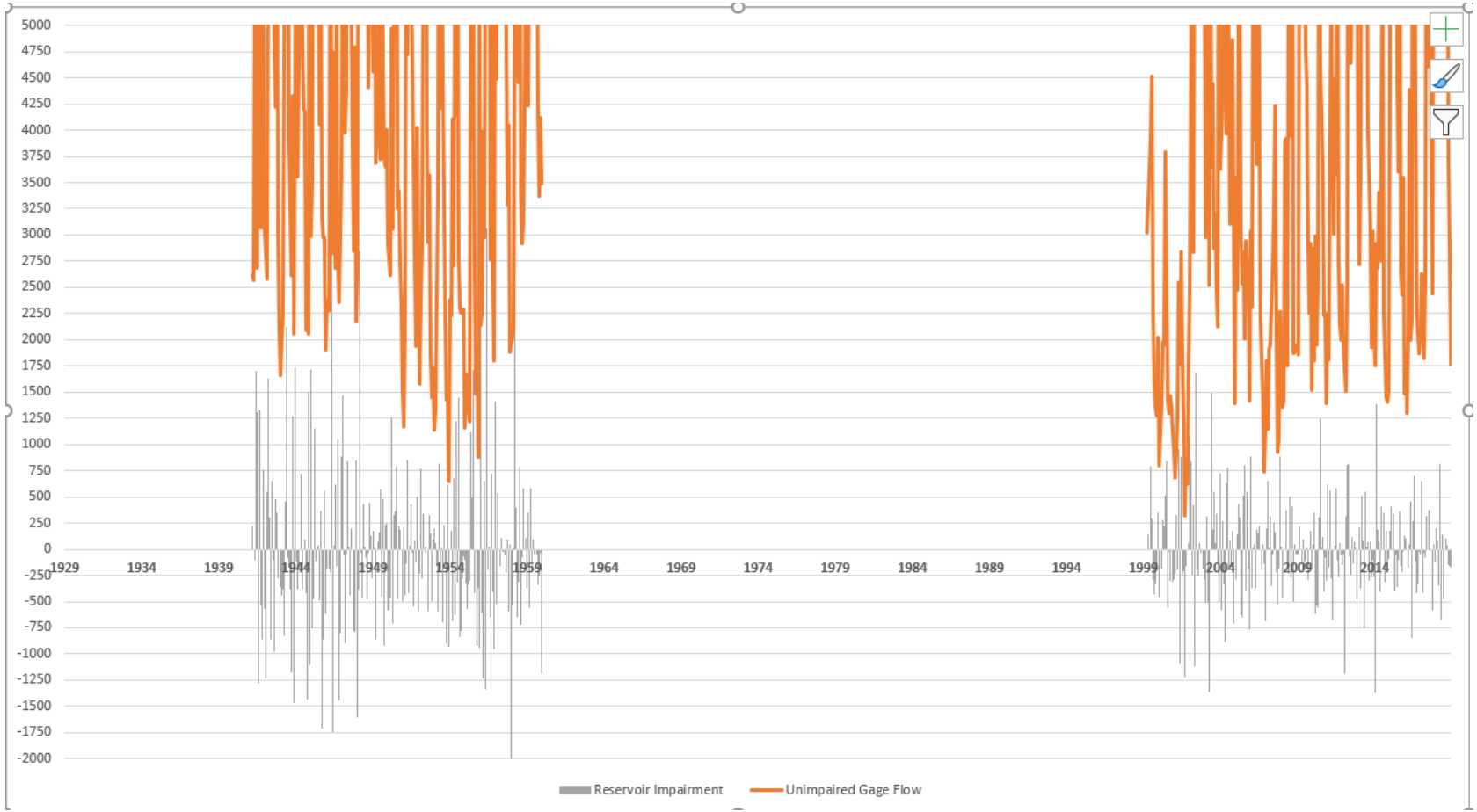
# Net Impairments (Not Incl. Reservoirs) – High Rock



# Net Impairments (Not Incl. Reservoirs) – High Rock



# Reservoir Impairments – High Rock

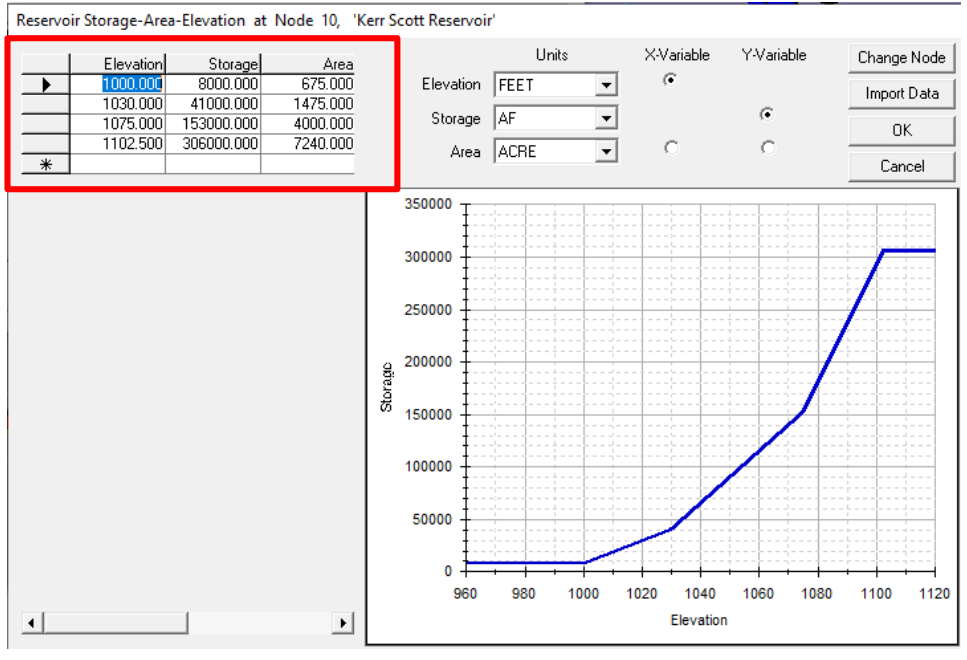


# Other Data for Basecase Run

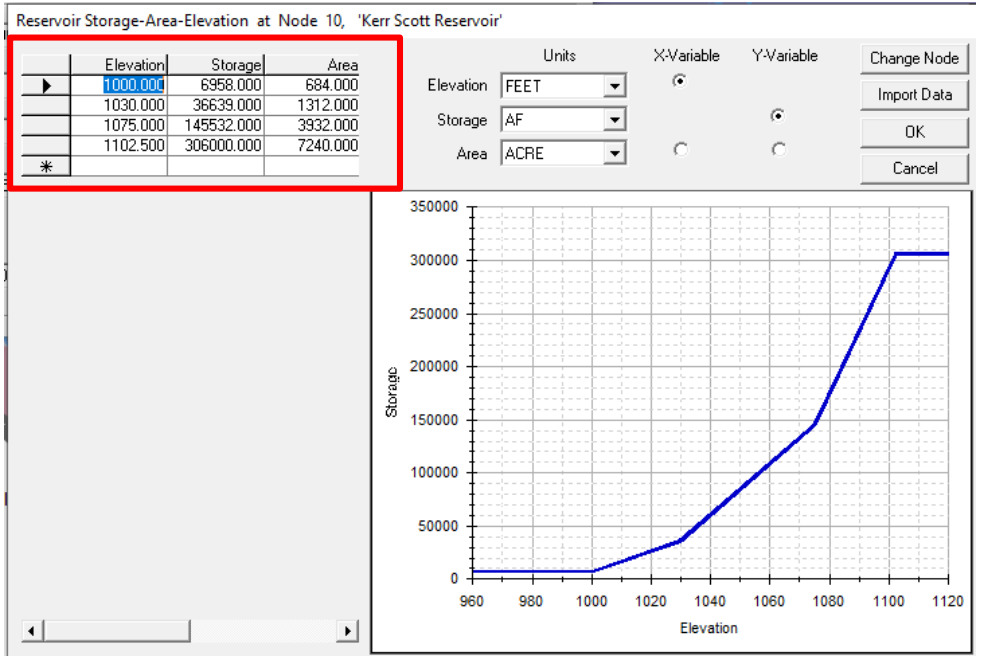
- Physical
  - Reservoir storage-area-elevation
  - Pumping capacity
  - Turbine capacity
  - Spill rating curves

# SAE for Kerr Scott

## Old (from project start)




## 2010 (survey up to 1075 feet)



# Operations

- Derive from reports, LWSPs, WSRPs, operating licenses, and personal contacts
- Include drought plans and minimum releases

# Drought Plans

- Almost 20 that are modeled – tied to reservoir storage/elevation; river flow; drought monitor, and/or river stage. Drought monitor used for LIP when available. % WTP capacity not modeled since that requires distribution system demand that can vary hourly.

**Water Shortage Response Plan Comparison Matrix: Triggers**

| Utility | Union Co | Albemarle[1] | Anson Co | Concord[1,2] | Davidson Water[1] | Davie Co[1] | Denton | Dobson | Elkin | Hamlet Water System | Handy Sanitary District | Jonesville |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source Water | Catawba River & Blewett Fall Lake (Anson County - Finished) | Tuckertown Reservoir & Badin Lake | Blewett Falls Lake | 2007 IBT from Catawba Basin (Charlotte Water - Finished) & Yadkin Basin (Albermarle - Finished), Purchase (Kannapolis - Finished) | Yadkin River | South Yadkin River & Yadkin River | Tuckertown Reservoir | Fisher River | Big Elkin Creek | Water Lake | Tuckertown Reservoir | Yadkin River |
| Level 1 or Voluntary Reductions | Catawba-Wateree LIP<br><br>Year-round irrigation restrictions to 3 days per week, regardless of drought status | Lake Levels:<br>High Rock Lake: -4.0 ft<br>Badin Lake: -4.0 ft | YPDLIP | US Drought Monitor:<br>0 Stage 0<br><br>Lake Levels:<br>High Rock Lake: YPDLIP<br><br>Inflow:<br>Lake Howell: WSACC<br><br>Stream Inflow:<br>YPDLIP | Lake Level:<br>Reservoir Levels on-site @ WTP: < 85%<br><br>Streamflows:<br>< 400 cfps<br><br>Demand:<br>7 day average > 16 mgd (80%) | US Drought Monitor:<br>0 or 1<br><br>Streamflows:<br>Compare to 7 day demand<br><br>System Specific Indicators:<br>7 day average demand as % of flow >25% | YPDLIP | None | Consideration shall be primarily given to the following criteria: water levels in the Big Elkin Creek, water levels in the Town's reservoir, capabilities of water production and distribution system, outlook for precipitation, daily water use patterns, seasonal and long-term weather patterns and availability of water from other sources. | None | YPDLIP | A state of emergency shall be deemed to exist whenever, in the opinion of the Board of Commissioners, the availability and suply of water is critical so that a mechanical malfunction or breakdown of the town's pumps or a rapid drawdown of the water supply would so deplete the water supply and availability of water as to threathen or cause to threaten the availability of water for human consuption, for firefighting purposes and other protection of lives and property, and the conservation of water is necessary in order to protect lives, safety and property within the town. |
| Level 2 or Mandatory Reductions I | Catawba-Wateree LIP<br><br>Demand: >80% of available capacity for the average of a 7 day period | Lake Levels:<br>High Rock Lake: -8.0 ft<br>Badin Lake: -6.0 ft<br>Tuckertown Reservoir: -2.0 ft | YPDLIP | US Drought Monitor:<br>1 Stage 1<br><br>Lake Levels:<br>High Rock Lake: YPDLIP<br><br>Inflow:<br>Lake Howell: WSACC<br><br>Stream Inflow:<br>YPDLIP | Lake Level:<br>Reservoir Levels on-site @ WTP: < 80%<br><br>Streamflows:<br>< 350 cfps<br><br>Demand:<br>7 day average > 17 mgd (85%) | US Drought Monitor:<br>1 or 2<br><br>Streamflows:<br>Compare to 7 day demand<br><br>System Specific Indicators:<br>7 day average demand as % of flow >50% | YPDLIP | None | | None | YPDLIP | |
| Level 3 or Mandatory Reductions II | Catawba-Wateree LIP<br><br>Demand: >90% of available capacity for the average of a 7 day period | Lake Levels:<br>High Rock Lake: -14.0 ft<br>Badin Lake: -8.0 ft<br>Tuckertown Reservoir: -3.0 ft | YPDLIP | US Drought Monitor:<br>2 Stage 2<br><br>Lake Levels:<br>High Rock Lake: YPDLIP<br><br>Inflow:<br>Lake Howell: WSACC<br><br>Stream Inflow: | Lake Level:<br>Reservoir Levels on-site @ WTP: < 75%<br><br>Streamflows:<br>< 300 cfps<br><br>Demand:<br>7 day average > 18 mgd (90%) | US Drought Monitor:<br>1 or 2<br><br>Streamflows:<br>Compare to 7 day demand<br><br>System Specific Indicators:<br>7 day average demand as % of flow >50% | YPDLIP | None | | None | YPDLIP | |

# LIP – Yadkin Project Requirements

## Low Inflow Protocol
## for the
## Yadkin & Yadkin-Pee Dee River Hydroelectric Projects

**GOAL**

The fundamental goal of this Low Inflow Protocol (LIP) is to take staged actions in the Yadkin-Pee Dee River Basin needed to delay the point at which available water storage in the Yadkin Hydroelectric Project (Federal Energy Regulatory Commission – FERC No. 2197) and the Yadkin-Pee Dee Hydroelectric Project (FERC No. 2206) (collectively, projects) reservoirs is fully depleted while maintaining downstream flows. This LIP is intended to provide additional time to increase the probability that precipitation will restore streamflow and reservoir water elevations to normal ranges. The amount of additional time that is gained during implementation of this LIP depends on the diagnostic accuracy of the trigger points, the amount of regulatory flexibility available to operate the projects, and the effectiveness of the projects' operators and the water users in working together to implement required actions and achieve significant water use reductions. It is assumed that water users in the Yadkin-Pee Dee River Basin not subject to this LIP must comply with all applicable State and local drought response requirements.

The Licensees will provide flow from storage in the projects' reservoirs to support hydroelectric generation and to provide Required Minimum Instream Flows in accordance with their respective new FERC licenses. During periods of normal inflow, reservoir water elevations will be maintained within their Normal Reservoir Operating Ranges. During times that inflow is not adequate to provide Required Minimum Instream Flows and maintain reservoir water elevations within their Normal Reservoir Operating Ranges, the Licensees will reduce releases for hydroelectric generation. If reservoir storage continues to drop and climatologic or hydrologic conditions worsen until trigger points defined in this LIP are reached, the Licensees will implement additional provisions of this LIP, including meeting with the designated agencies and water users to discuss the need for actions pursuant to this LIP. If conditions worsen, progressive stages of this LIP will allow additional use of the available water storage inventory, while conserving water storage volumes through required reductions in LIP Flows and required reductions in water withdrawals.

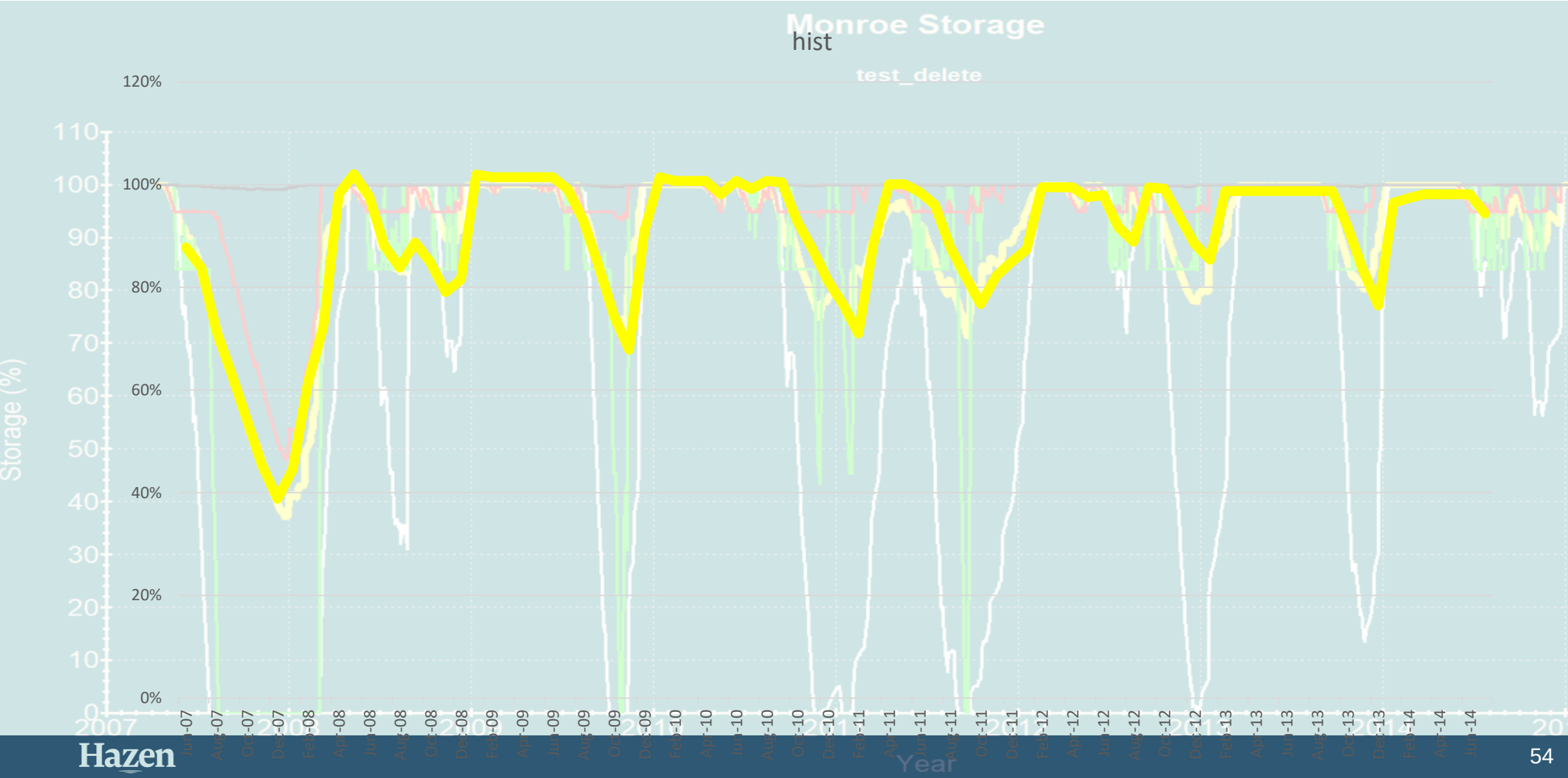
### 3.1.4.4 Updating the LIP

During the term of this license, the Licensee shall consult with the YPD-DMAG at least once every five (5) years to review and consider updating the LIP. The use of the period of record 1974 through 2003 to calculate the Historic Stream Gage Three-Month Rolling Average flows set forth in Table LIP-1 of this Article shall be evaluated every five years during such review. On the basis of such consultation, review and consideration, the Licensee may propose modifications to this Article for the Commission's review and approval.

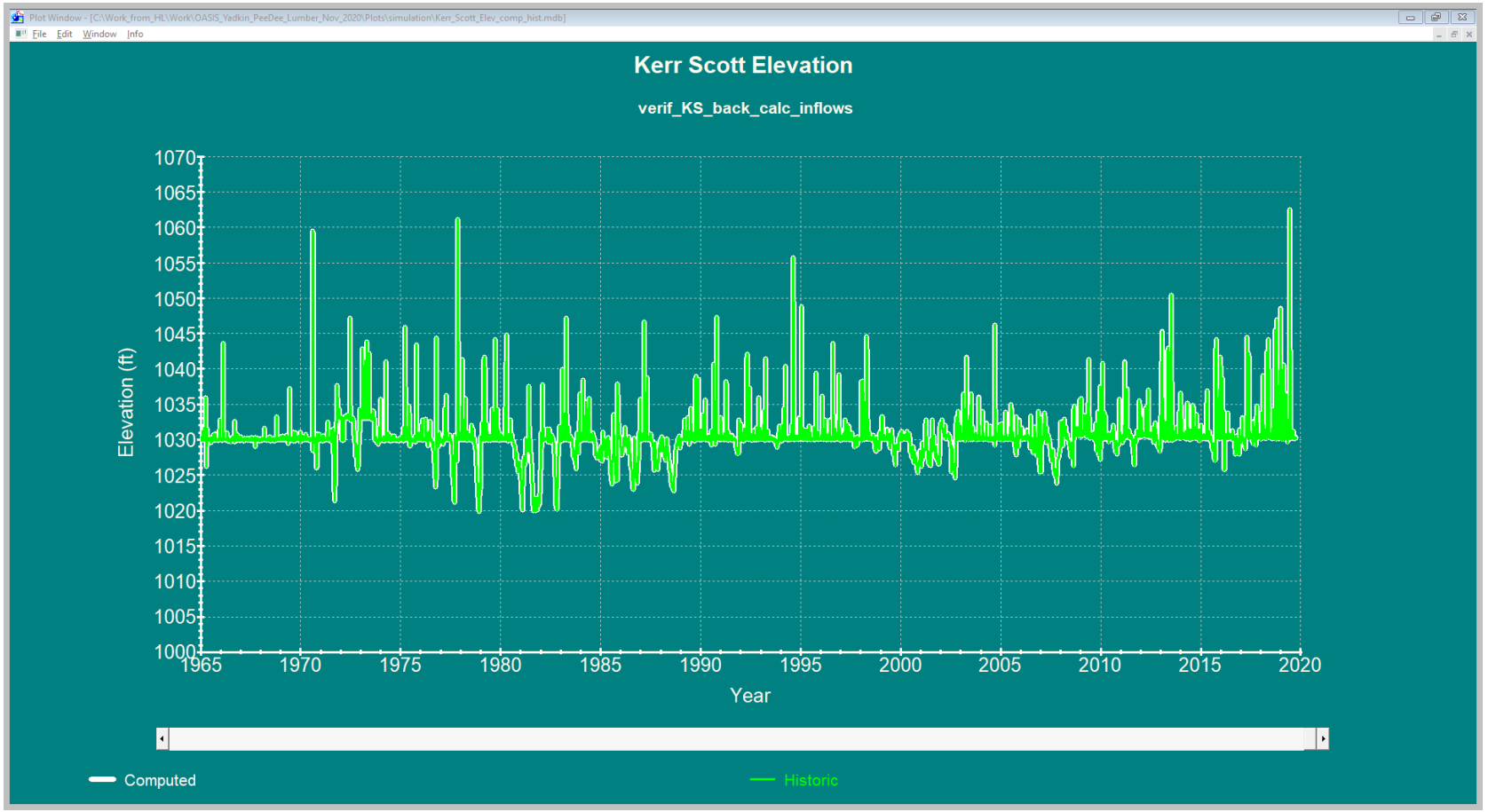
# Verification of Basecase Run

- Inflows
- Operating rules

# Monroe – Example -- At 6 mgd avg.

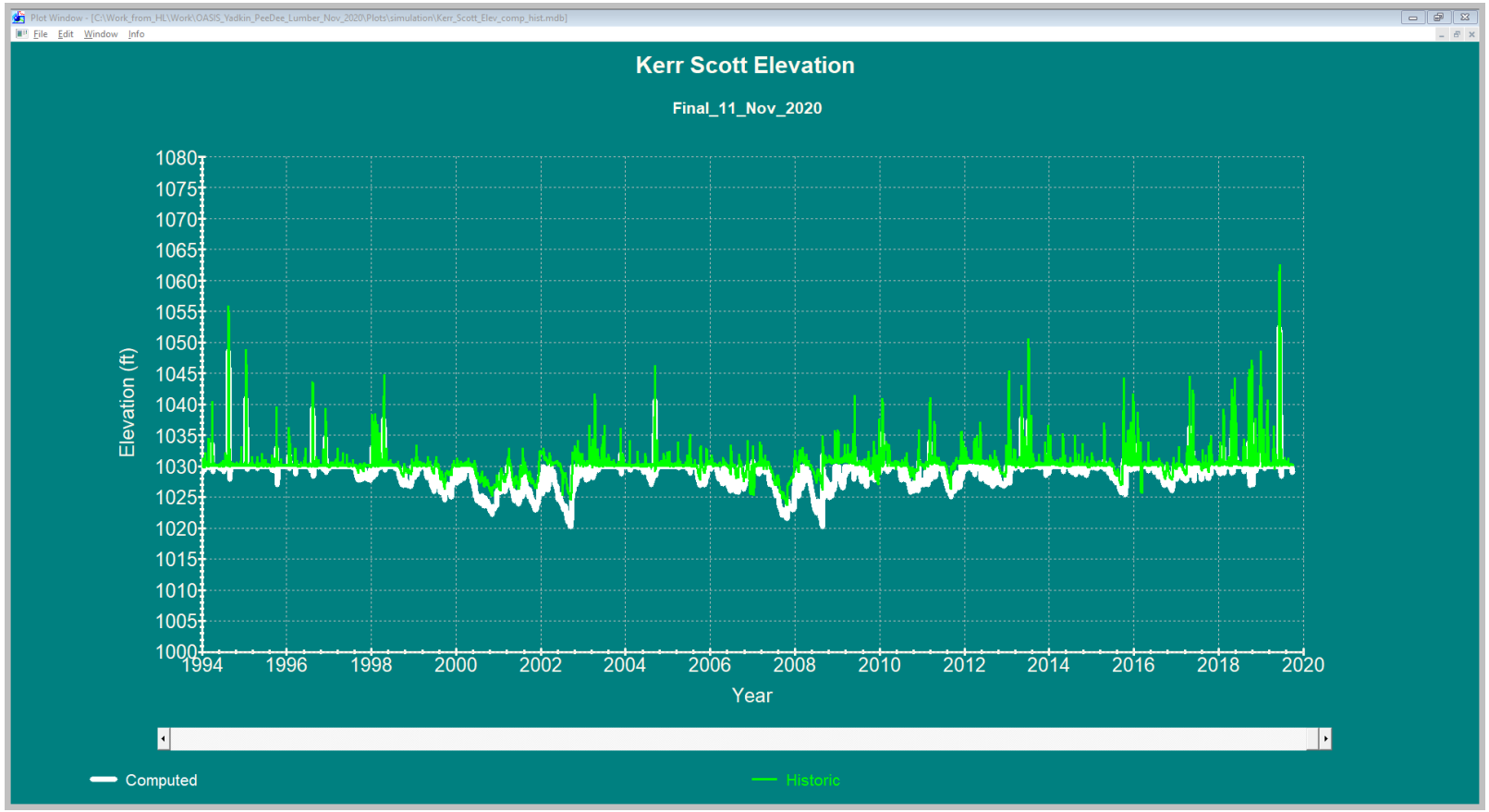


# Kerr Scott




Note: operation changed in 1993 with Water Control Plan, including new low flow protocol

# Kerr Scott

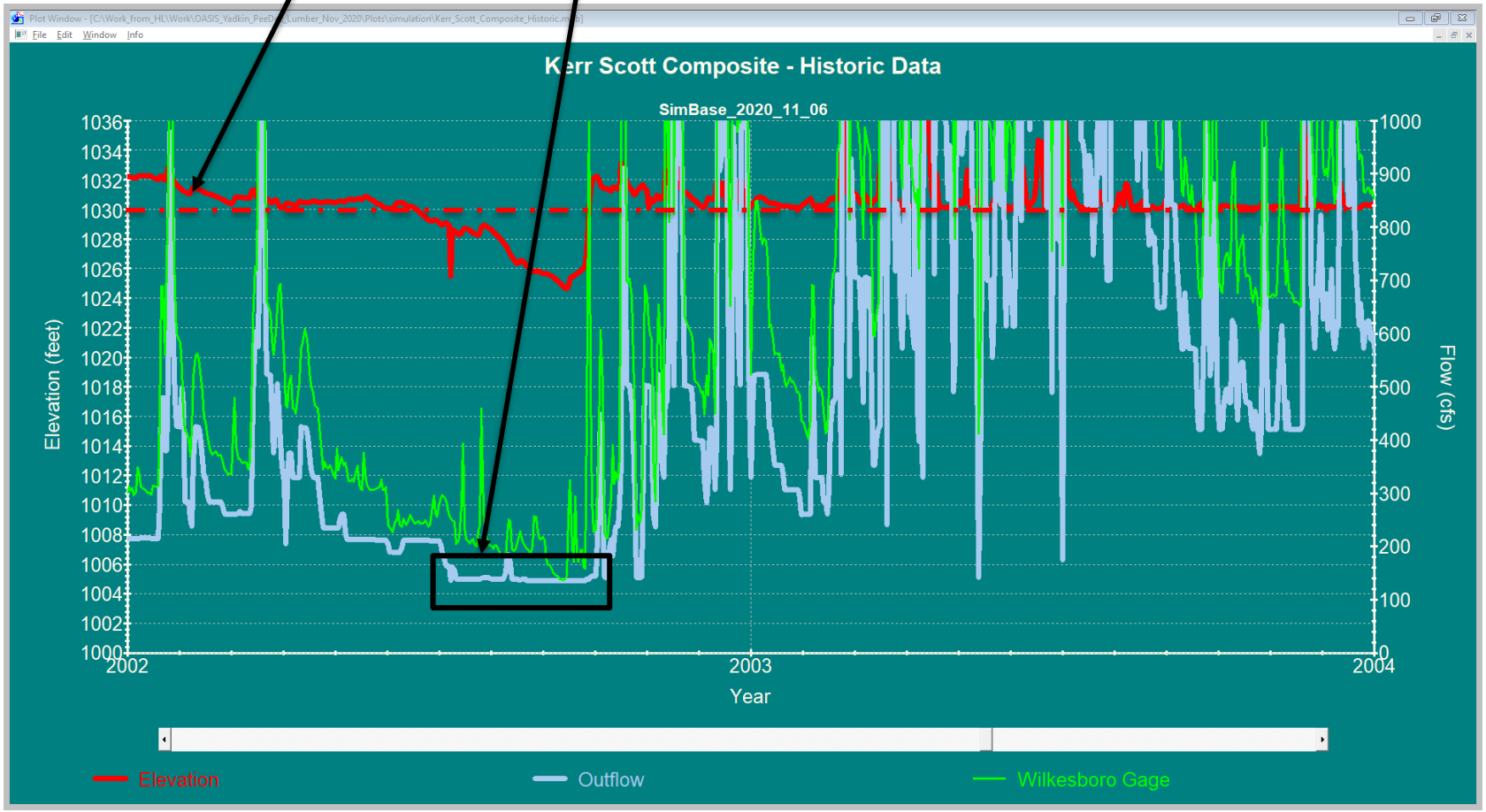



Note: shown since 1993 when revised Water Control Plan went into effect

Historic return to guide curve can be delayed due to hedging on flooding concerns downstream and also holding water to delay drawdown during drought

# Kerr Scott - Historic

Historic release sometimes less than minimum required (here, normal minimum is 125 cfs only when < 1023 feet)



# Kerr Scott - Simulated

# High Rock

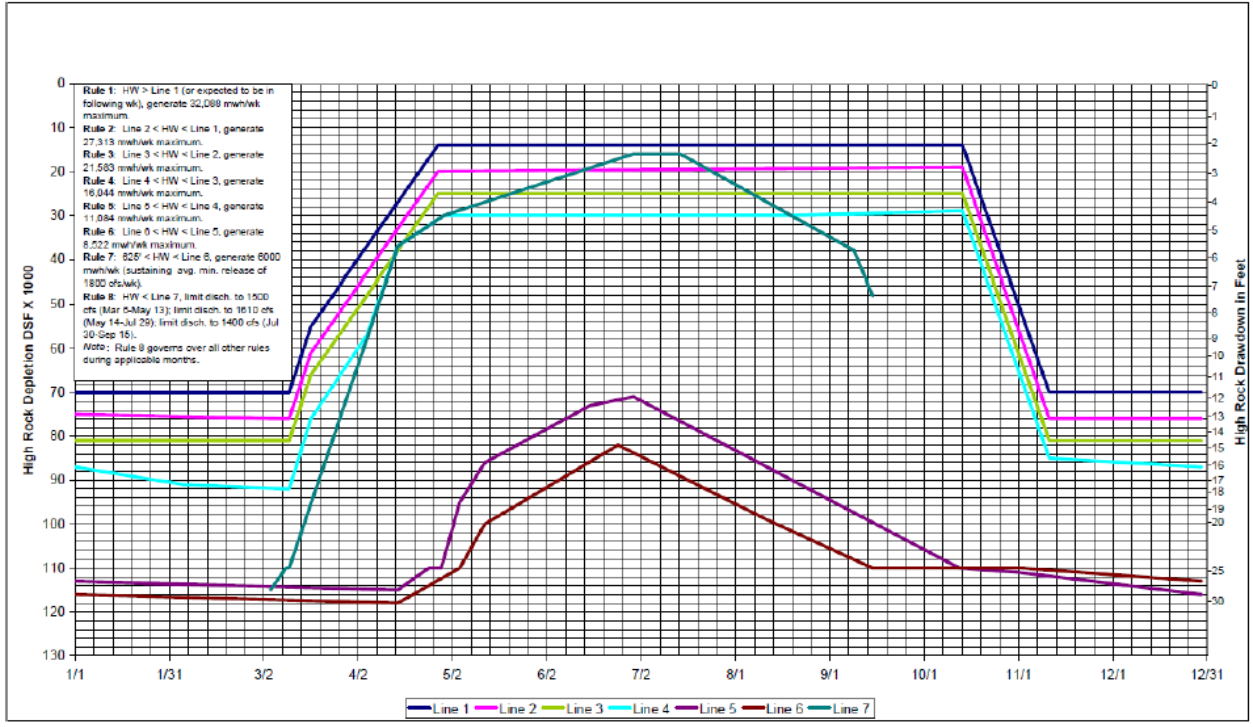

Plot Window - [C:\Work_from_HL\Work\OASIS_Yadkin_PeeDee_Lumber_Nov_2020\Plots\simulation\High_Rock_Elev_comp_hist.mdb]
File Edit Window Info
High Rock Elevation
verif_HR_back_calc_inflows
Elevation (ft)
630
628
625
623
620
618
615
613
610
608
605
603
600
598
595
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Year
Computed
Historic

# Documents Used to Model Mainstem Operations

- HDR Model Logic and Verification Report from 2014
  - **Pulled some information from the 2002 APGI and 2003 Progress Energy Initial Consultation Documents**
  - **CHEOPS model inputs for 2014 Assessment of Union County IBT**
- Relicensing Settlement Agreement for APGI and Comprehensive Settlement Agreement for Progress Energy in 2007
- License Documents for APGI in 2016 and Duke Energy in 2015

# Old License Operation for Yadkin Projects

**FIGURE 2-2**
**HIGH ROCK DEVELOPMENT OPERATING GUIDE.** [4]




Alcoa Power operated its Yadkin Project in accordance with a 1968 headwater benefits agreement with the licensee of the Yadkin – Pee Dee Project. According to the 1968 agreement, Alcoa Power regulates weekly average stream flow from Falls Reservoir to provide a flow not less than 1,500 cubic feet per second (cfs) during the 10-week period preceding the recreation season (May 15 through September 15); 1,610 cfs from May ….

# Iterations for a New License

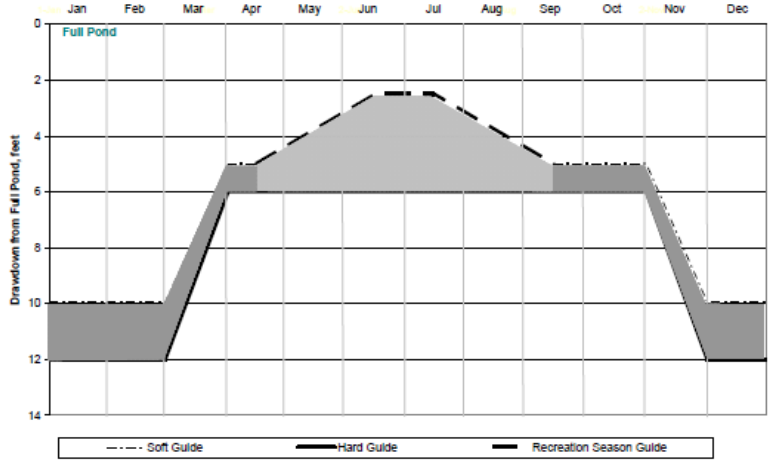
Modeled by HDR for Union County IBT work circa 2014

### B.2.1.2 Proposed Operations

*Reservoir Operations*

APGI proposes that under the new license, High Rock will be operated in accordance with a revised Guide Curve (Figure B-2) that features three basic guides: a Hard Guide, a Soft Guide, and a Recreation Season Guide (April 15 to September 15). During normal operations, APGI will maintain the reservoir elevation at or above the Soft Guide or the Recreation Season Guide elevation. Generation is not restricted for normal operations. If at any time the water level at High Rock falls below the Soft Guide or Recreation Season Guide and above the Hard Guide curve elevation (dark shaded section), APGI will reduce its generation and water releases from High Rock to the flow equivalent of no more than 1,500 cfs weekly average discharge until such time that the High Rock reservoir level returns to or above the Soft Guide or Recreation Season Guide curve. Operation in this range is expected to occur infrequently, and would be caused by conditions such as: actual inflows not meeting projected inflows; human error; equipment malfunction or failure; drought periods; or electrical system emergency (e.g., transmission bottlenecks, real and reactive power support, load following support, etc.) as discussed in the proposed Hydro Project Maintenance and Emergency Protocol (HPMEP) for the Project (see Exhibit B.6.4).

**Figure B-2: Proposed High Rock Guide Curve**



# Basin-Wide Operations

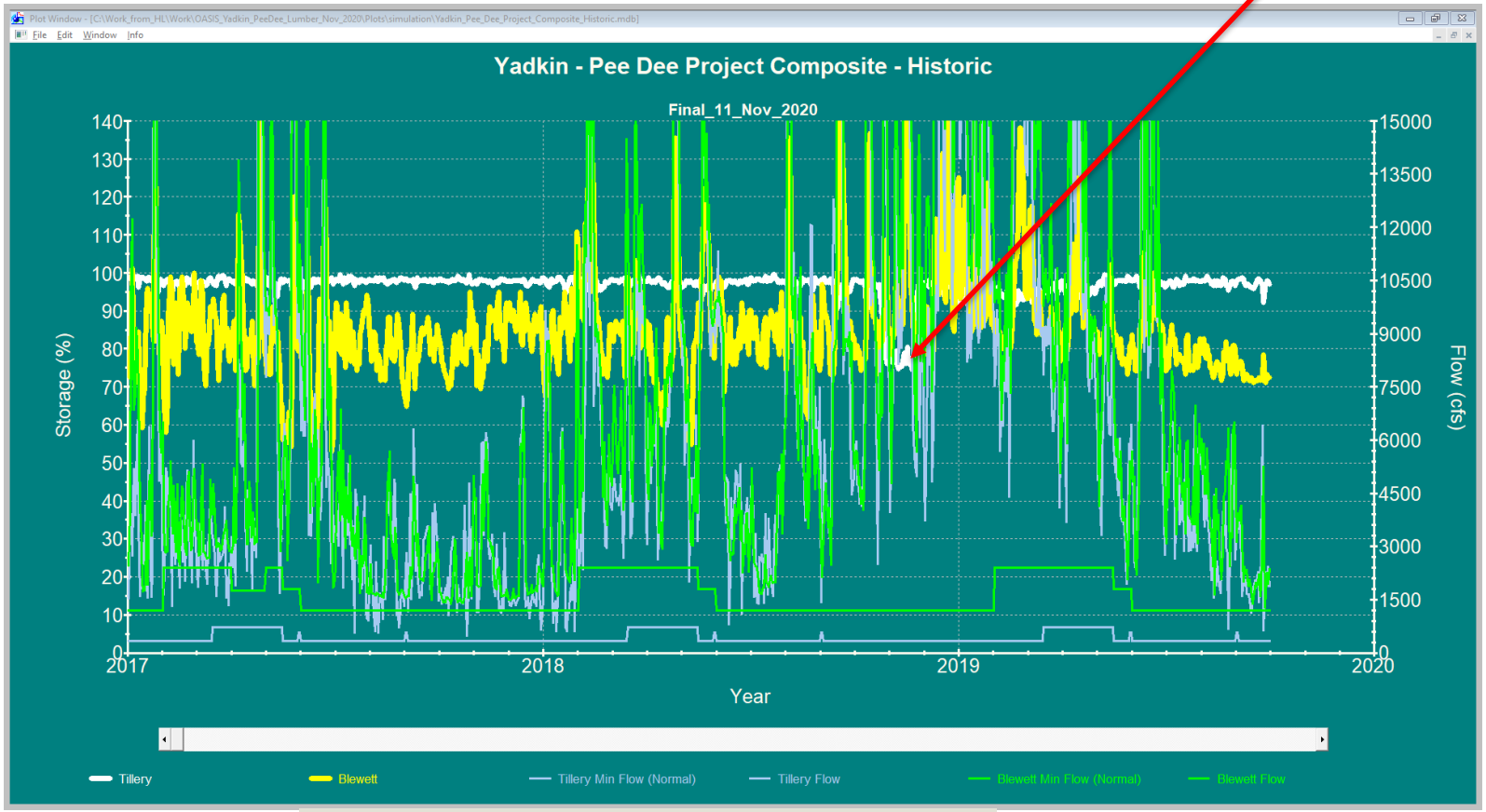
- Mostly independent
  - **Reservoirs upstream will not make releases for users downstream unless minimum flow requirements apply**
  - **Kerr Scott will provide additional release from Winston-Salem's account during low flow/high demand**
  - **Kerr Scott will limit releases down to Wilkesboro for flood control**
- Coordination among entities with multiple reservoirs, intakes, and WW discharges (e.g., WSACC, Anson County, Moore County in Lumber)
- Coordination through sale and purchase agreements, regular and emergency
- Coordination during drought conditions through Low Inflow Protocol

# Hydro Operations

- Set up to exploit the permitted operating band per the license agreements
  - **Model will generate down to the normal minimum elevation (NME) up to turbine capacity**
- Limited the operating range based on historic data (since 2017 when both companies were operating with new licenses)
- Not capturing day-to-day operations that are based on power market prices and demand
  - **Customized models can be developed as off-shoots to model (e.g., optimal dispatch for Dominion Virginia on the Roanoke River)**

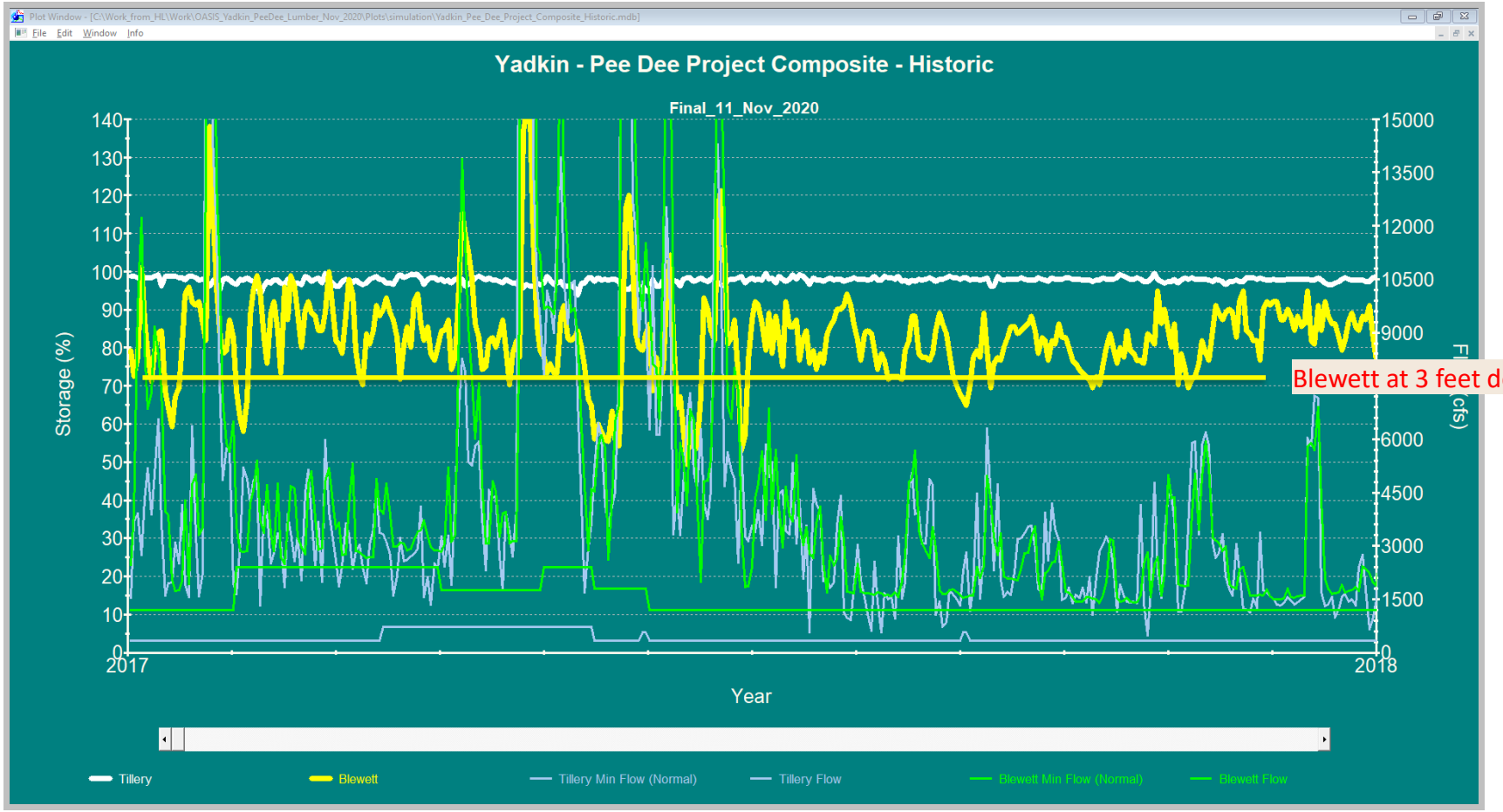
# YPD Project - Historical Operation

Maintenance (Ed Bruce believes this was the case for Tillery)



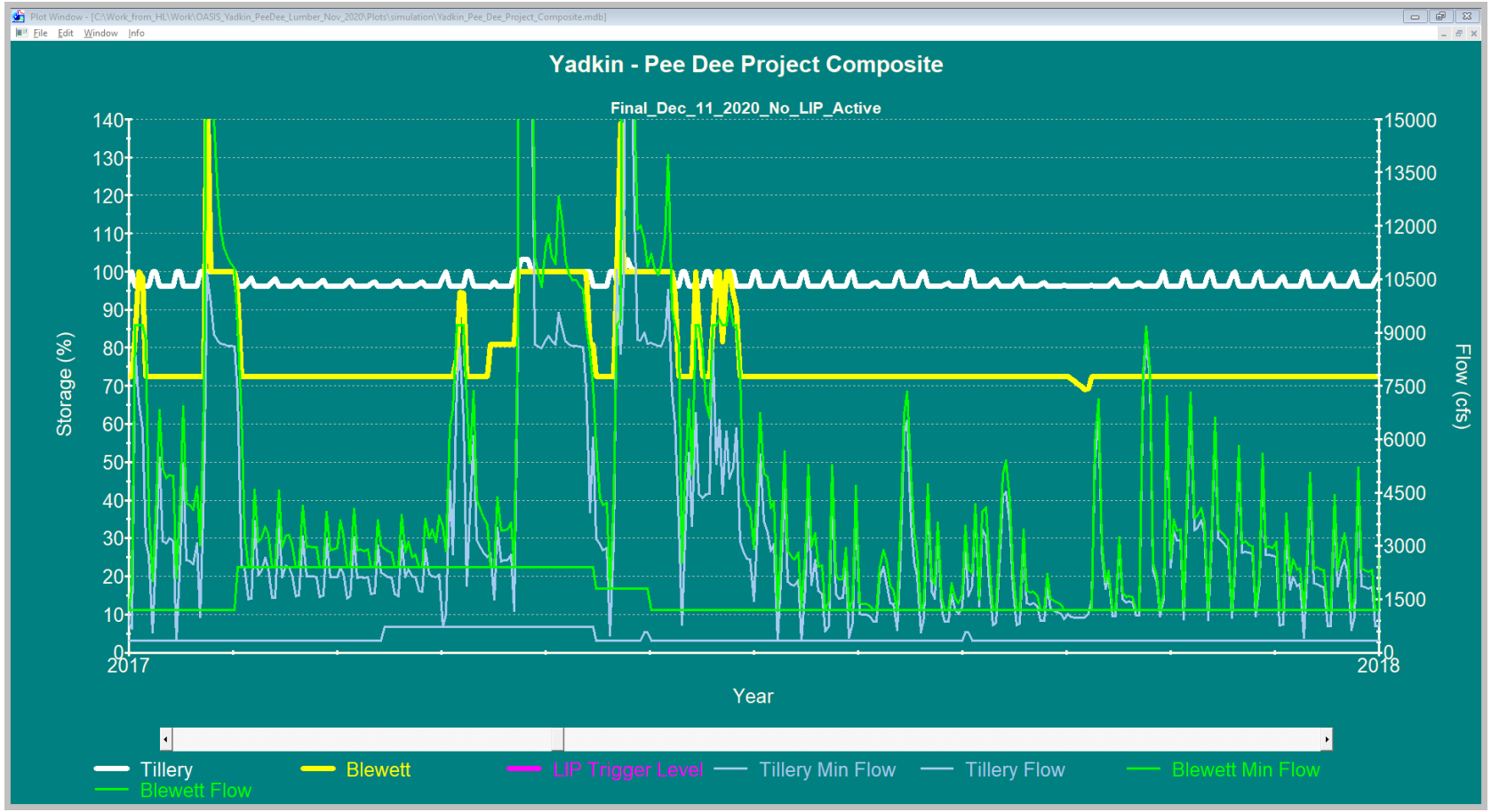

Shown is post-2017 after license was renewed so we have representative operations.
Here normal min flow requirement is shown; for Blewett, it would be adjusted if LIP were activated

# YPD Project - Historical Operation

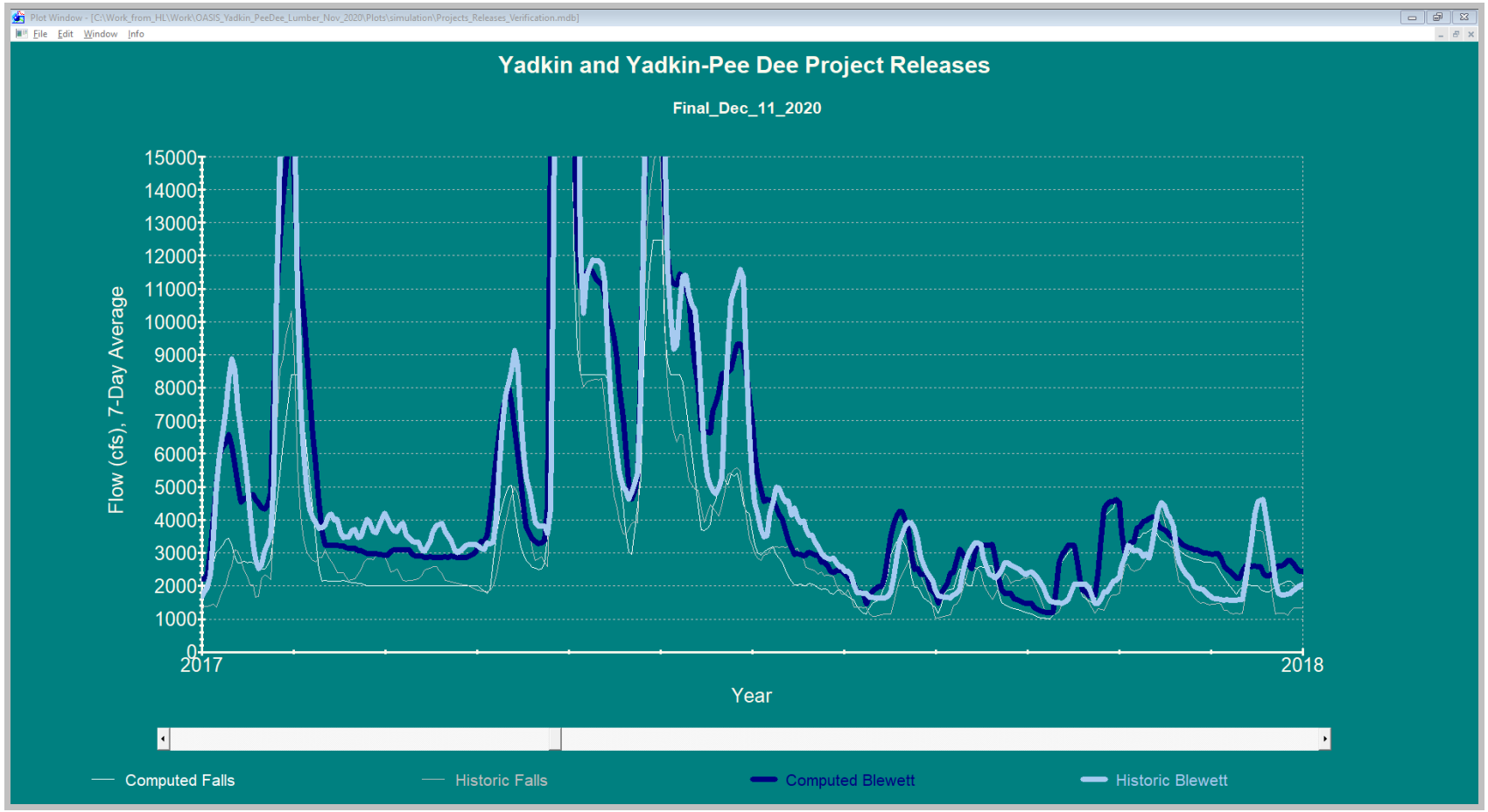



Blewett at 3 feet down

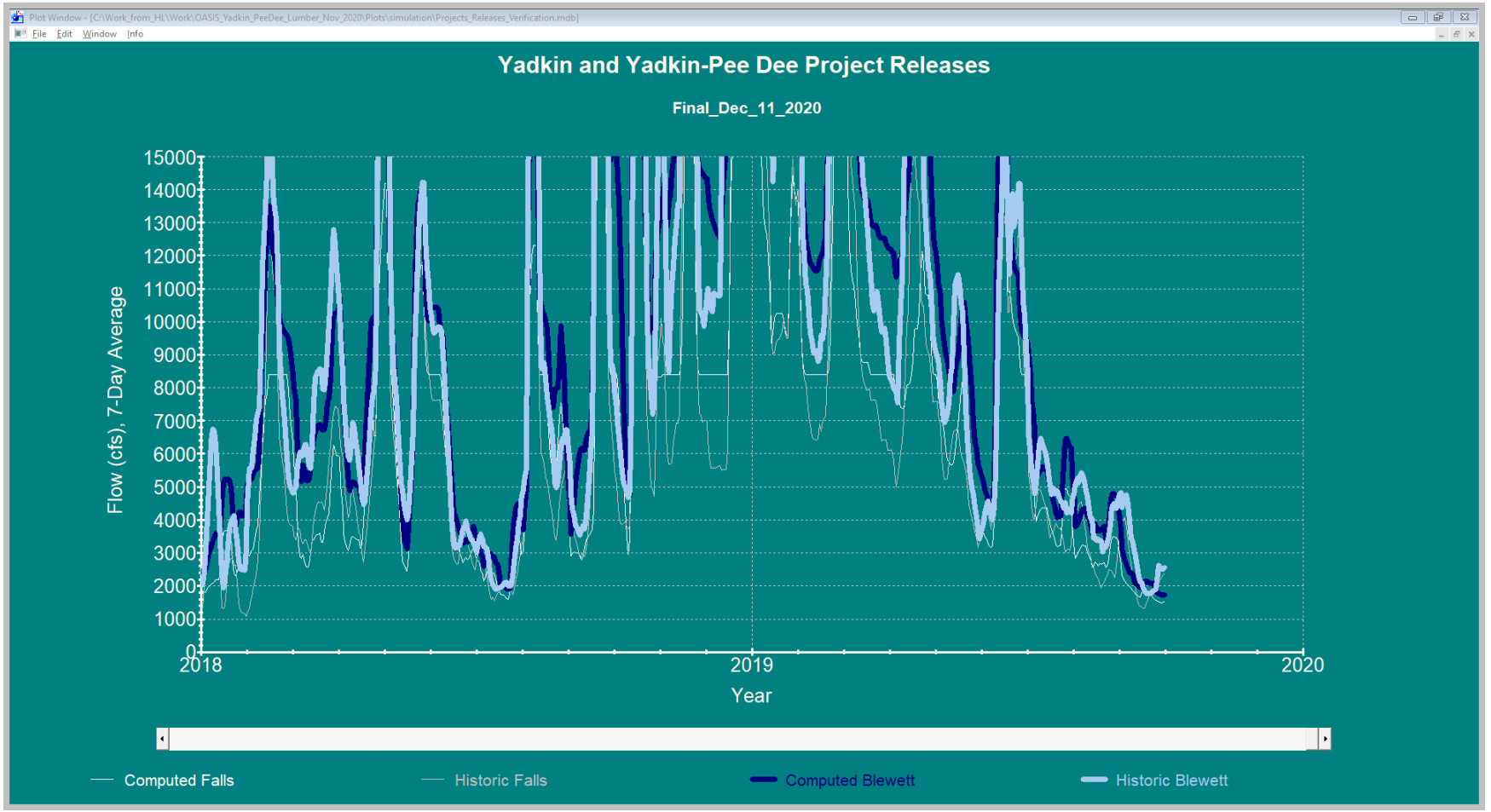
# YPD Project - Simulation



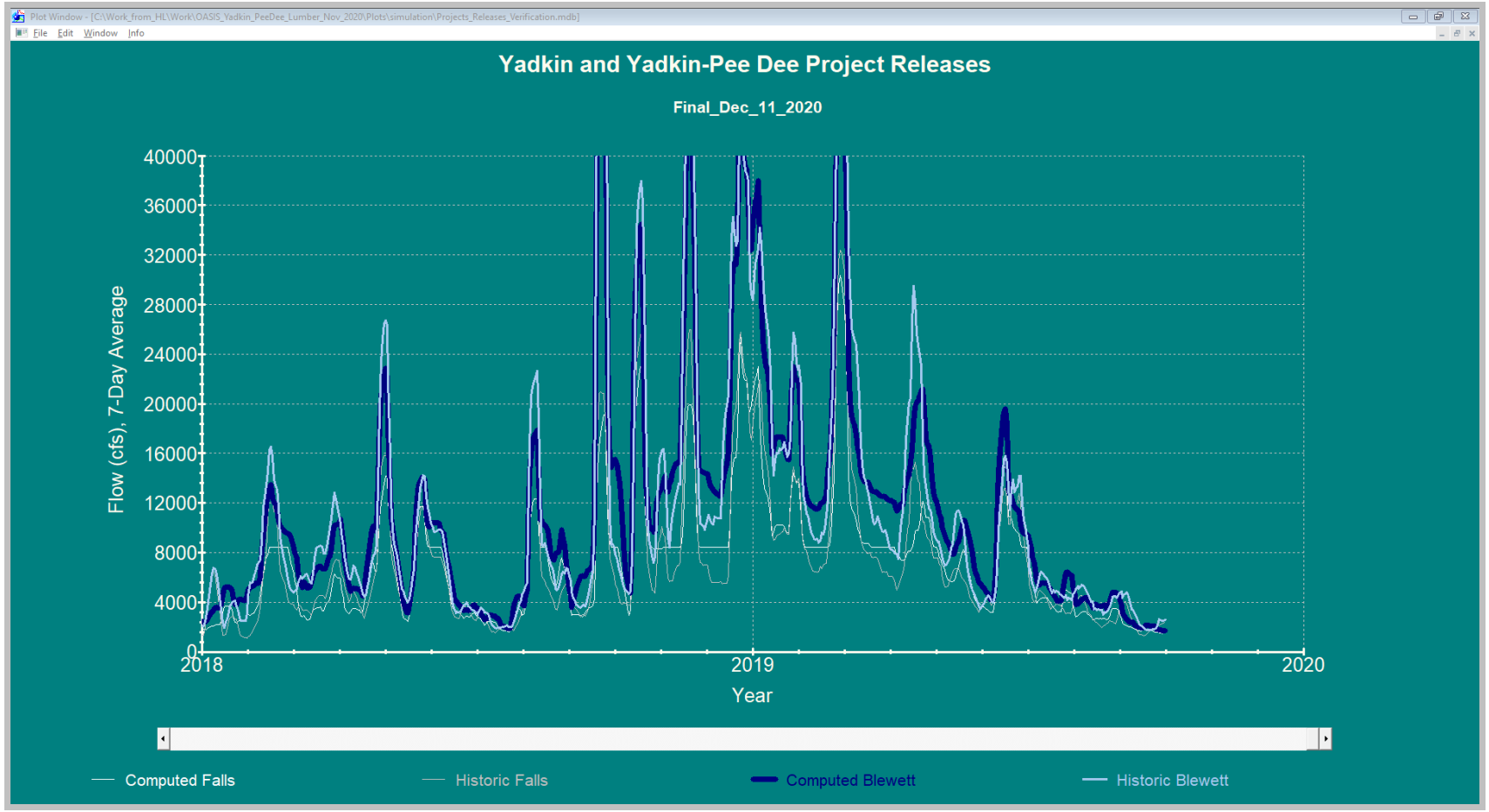
# YPD Project - Simulation



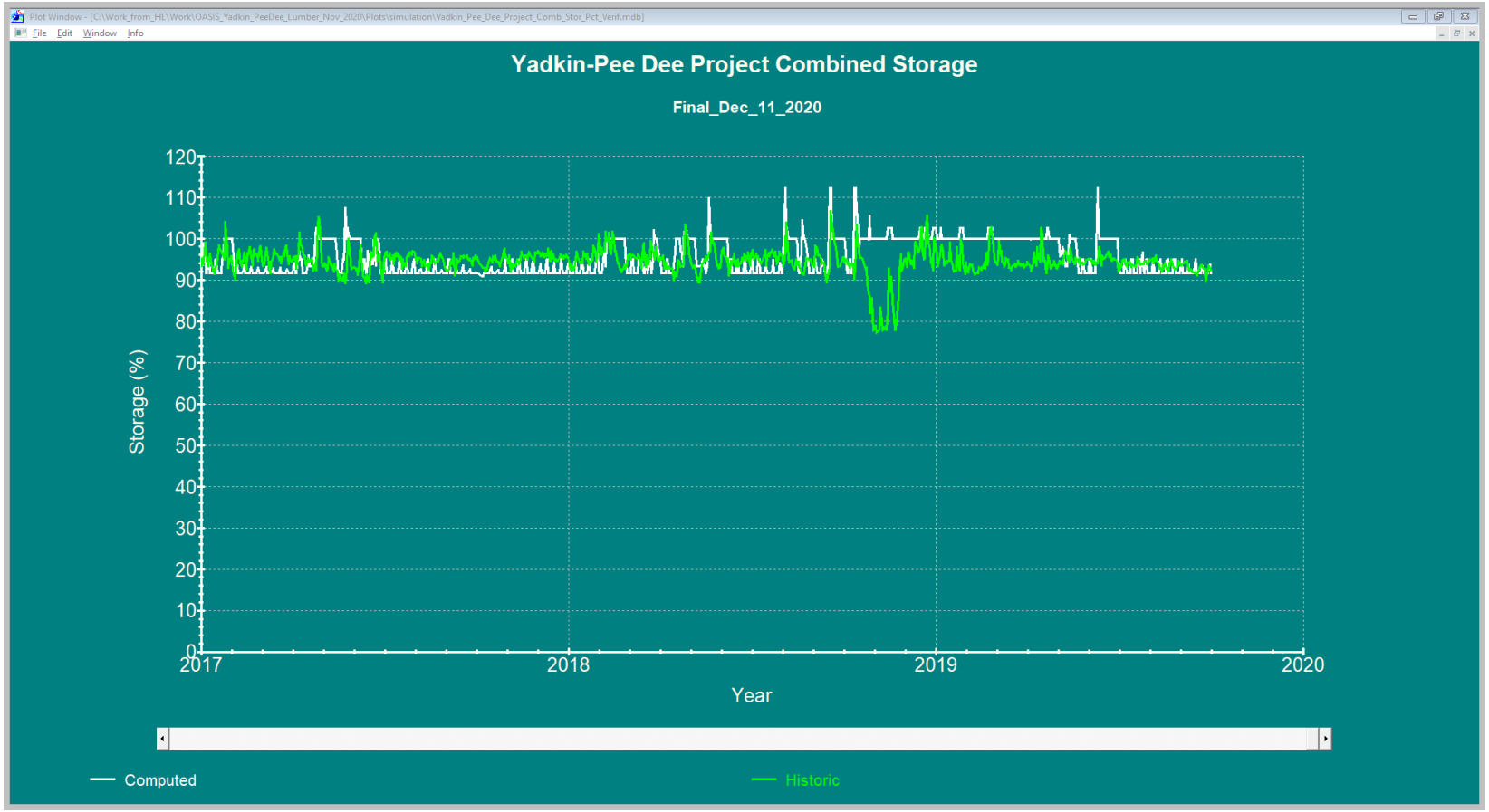
# YPD Project - Simulation



# YPD Project - Simulation

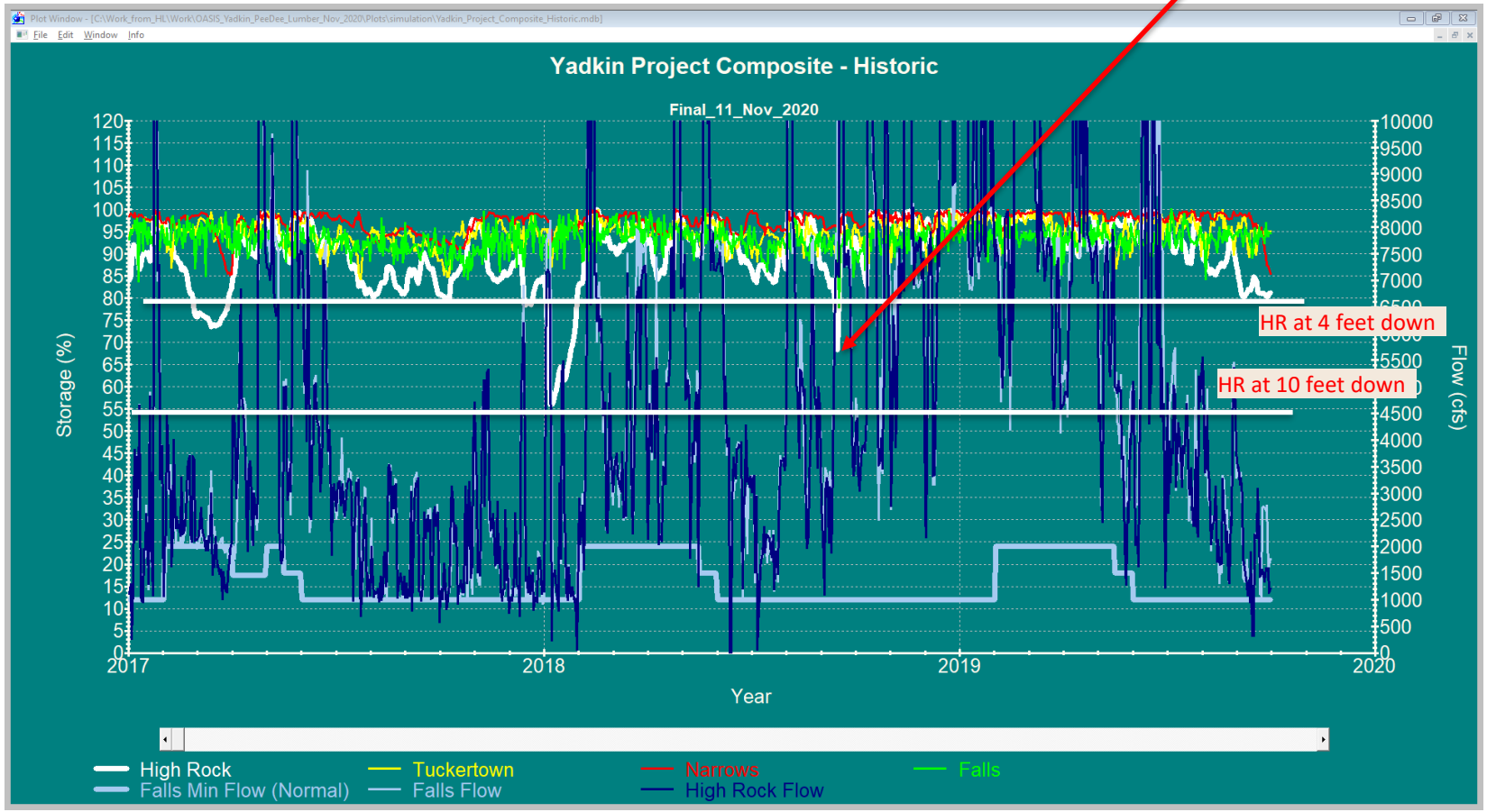


# YPD Project - Simulation

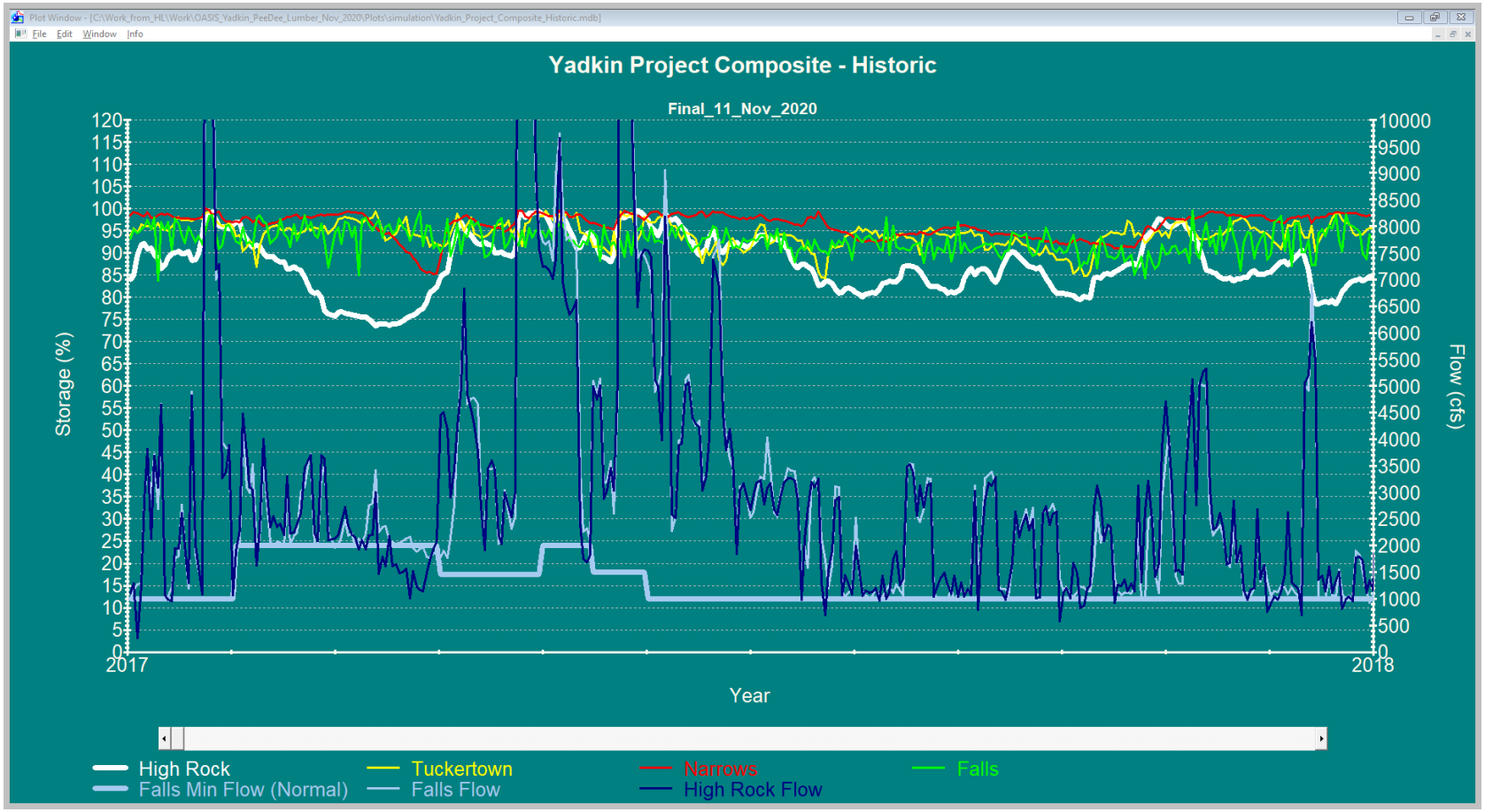


Deviation below 4 foot September NME to prepare for Hurricane Florence

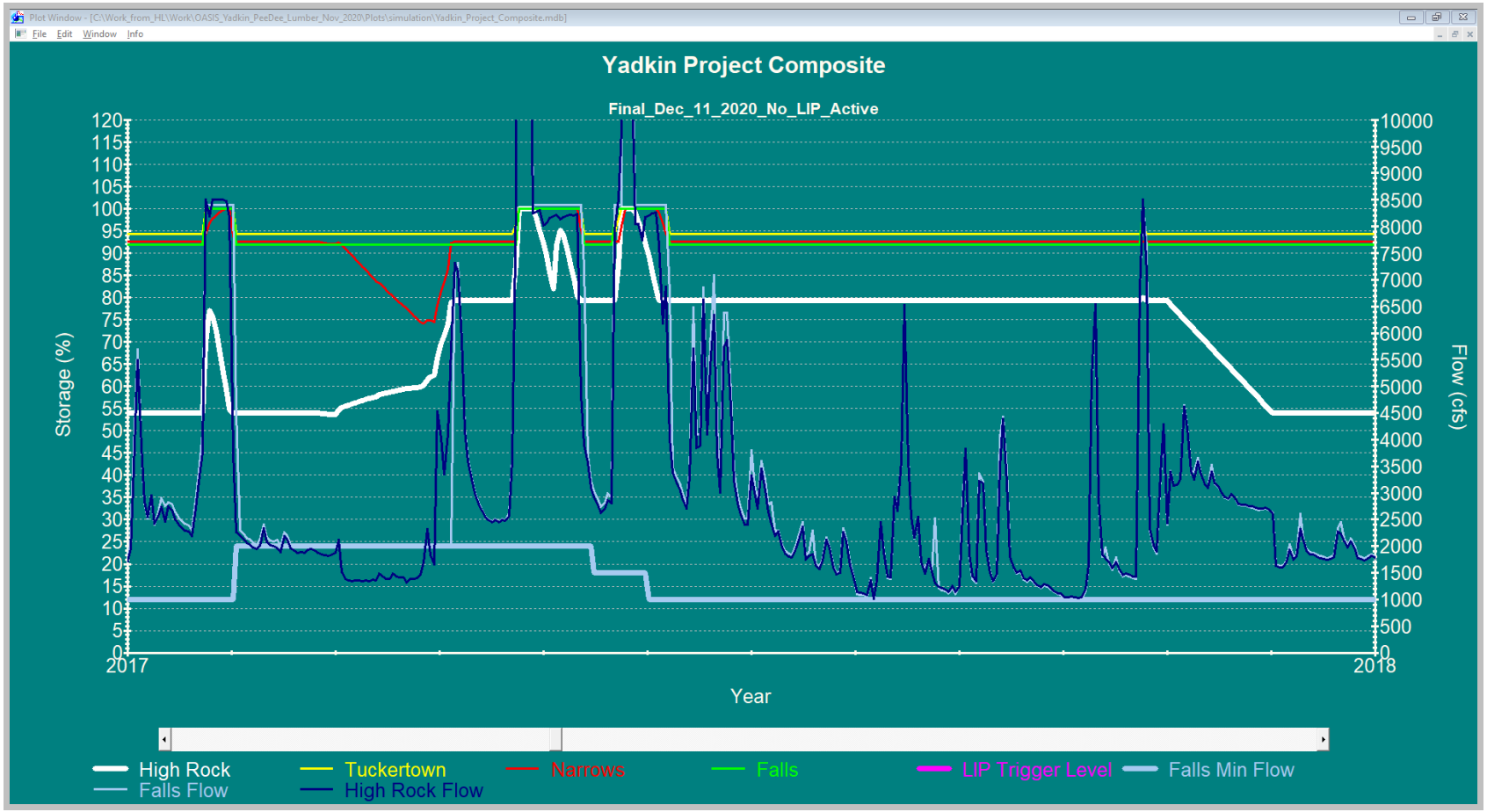
# Yadkin Project - Historical Operation



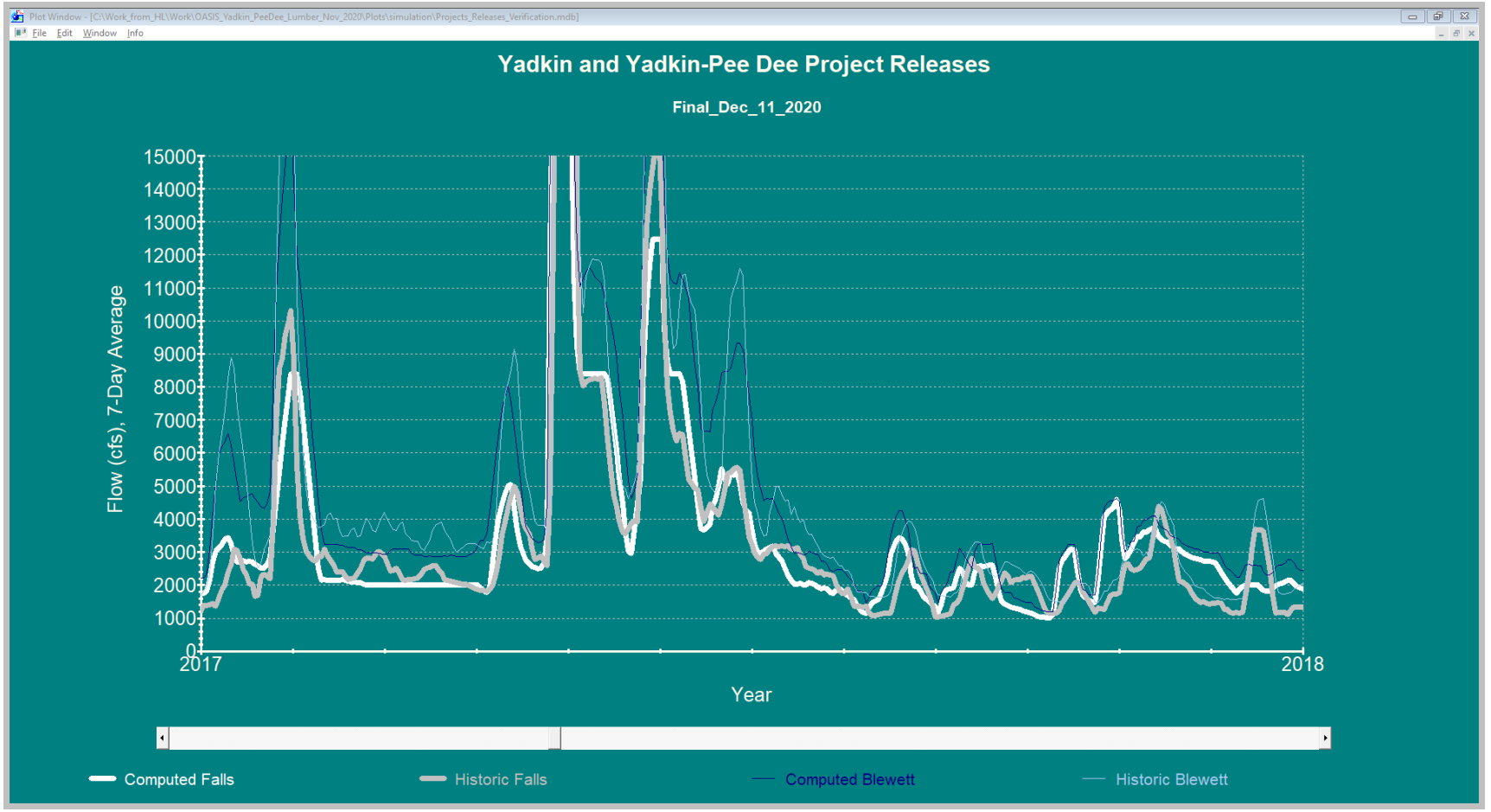
# Yadkin Project - Historical Operation



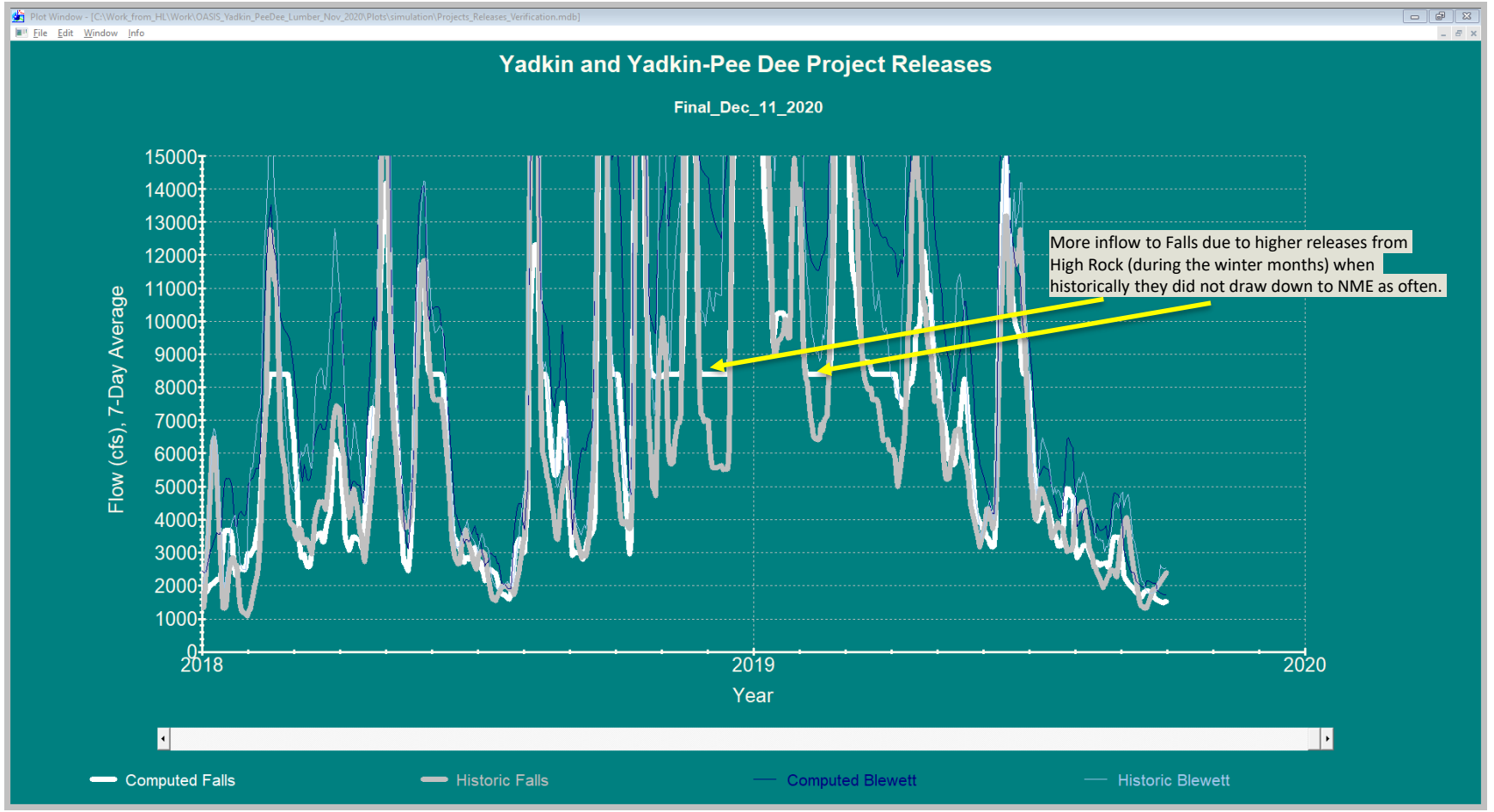
# Yadkin Project - Simulation



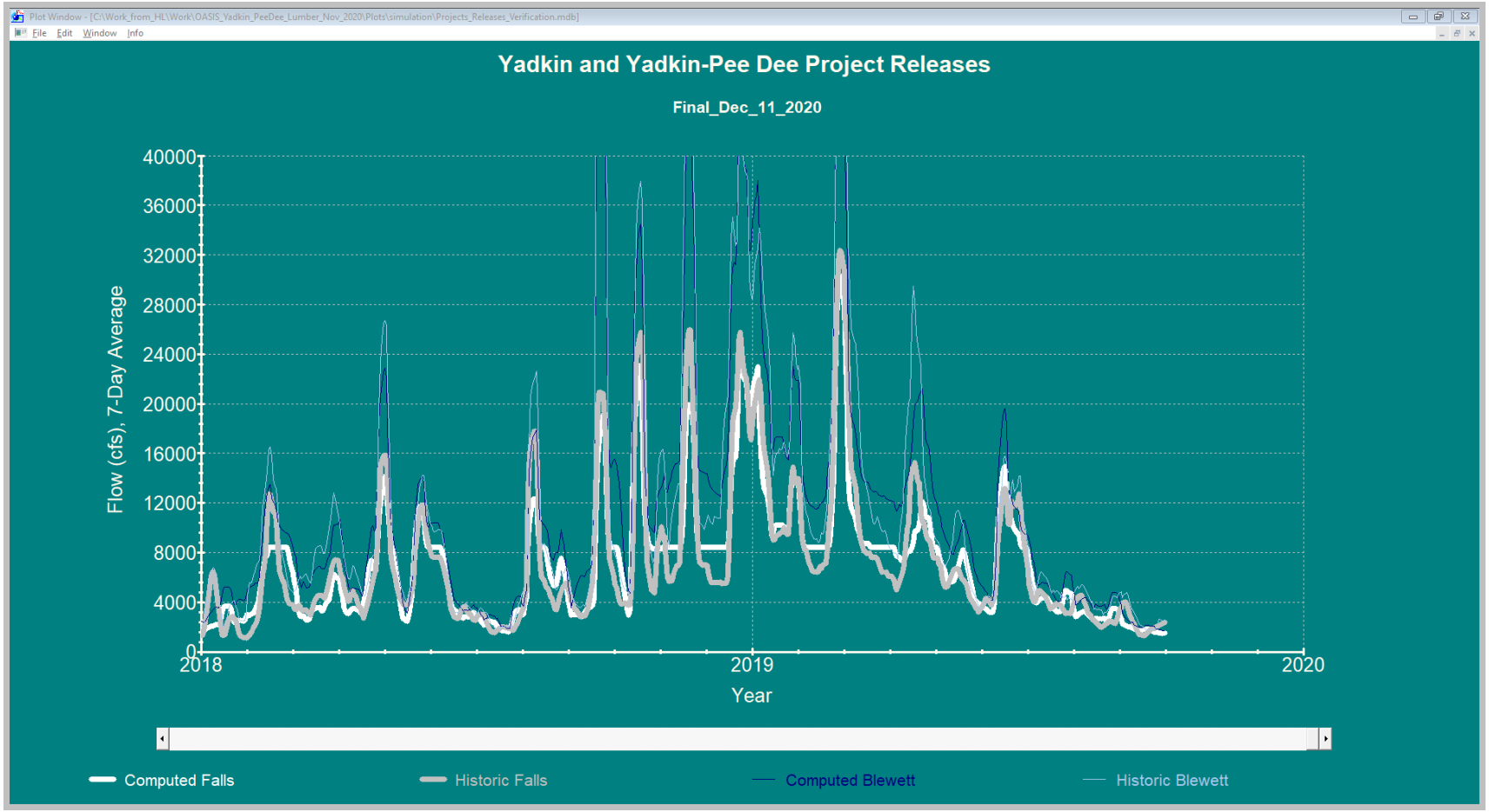
# Yadkin Project - Simulation



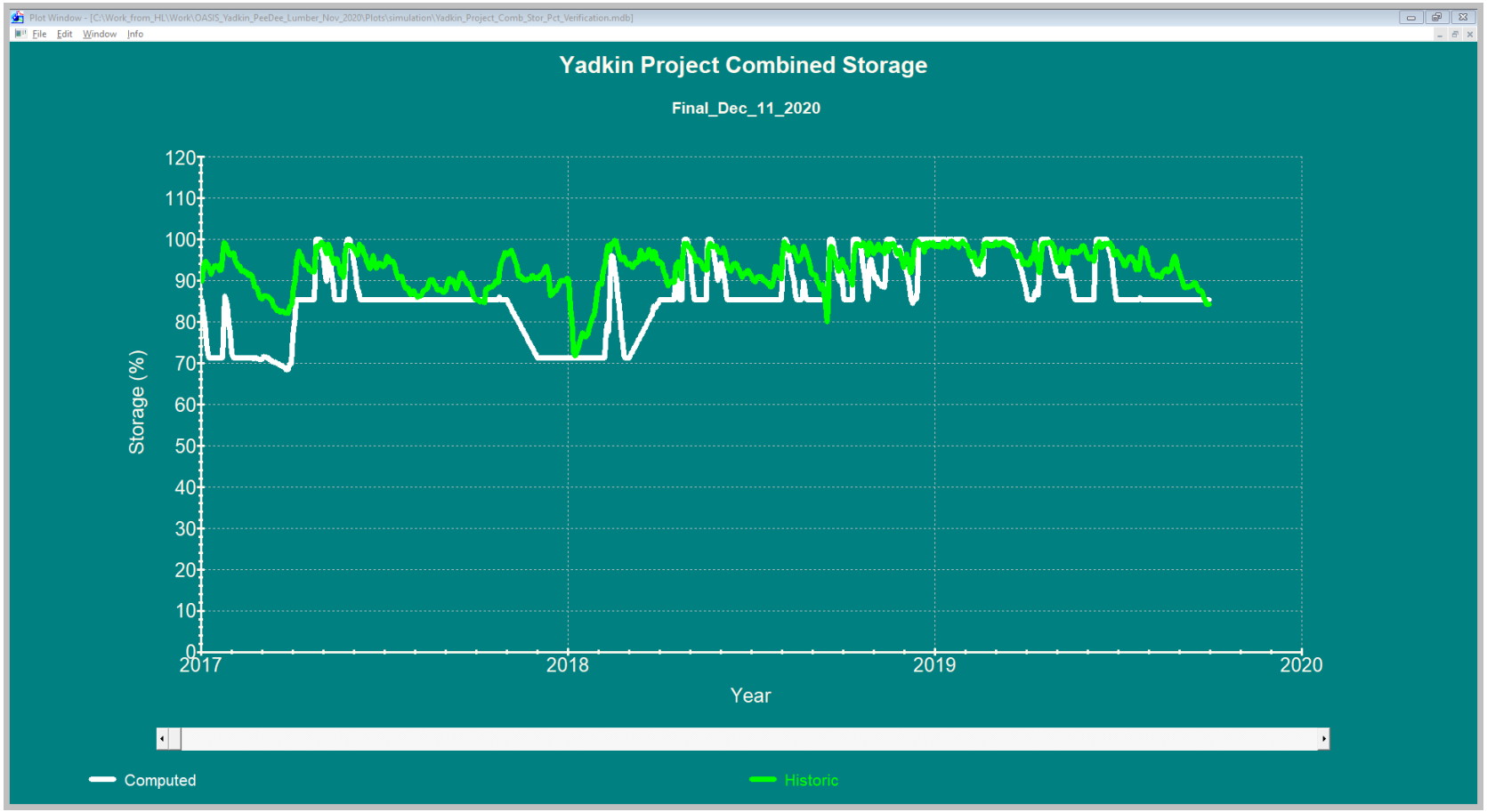
# YPD Project - Simulation



# Yadkin Project - Simulation



# Yadkin Project - Simulation



# Low Inflow Protocol

- Implemented in Feb. 2007
- High Rock operations impacting elevations may have changed between then and when license was issued in 2017
- Monthly determination, influencing Falls and Blewett minimum releases and water withdrawals (stages >=1) and hydro peaking (stages >= 0)
- Drought monitor based on national product (available since 2000), potentially refined for regional use
- DMAG to review every 5 years per license conditions as it relates to drought monitor (national vs. regional), gaging estimates and long-term averages, and proportional drawdown of reservoirs

**December 1, 2019: LIP Stage -1 Normal**

High Rock HWEL = NME plus 9.4 = 623.3 USGS Datum (NGVD29), 654.4 YAD

Current 3-mo rolling avg. inflows = 2,778 cfs

| | USGS Gage | | | |
|---|---|---|---|---|
| | Yadkin River at Yadkin College 2116500 | South Yadkin River Mocksville 2118000 | Abbotts Creek at Lexington 2121500 | Rocky River Near Norwood 2126000 |
| September | 1491 | 165 | 24 | 111 |
| October | 2111 | 224 | 54 | 273 |
| November | 2945 | 322 | 135 | 479 |
| 3 mo. avg. | 2182 | 237 | 71 | 288 |

Hist. 3-mo rolling average inflows = 3,550 cfs (Inflow Ratio = 0.78)
Drought Index Ratio = (1+1+0)/3 = 0.67
Last Month LIP Stage = Stage -1

***Evaluation Criteria for LIP Stage Implementation:***

The LIP *must* be implemented beginning at Stage 0 and, if the combination of conditions becomes more severe, the Stages *must* increase in one Stage increments.

Stage 0: High Rock HWEL < NME minus 0.5 **NO**
**OR** High Rock HWEL < NME minus 0 **AND** US Drought Monitor => 0 **NO**
**OR** High Rock HWEL < NME minus 0 **AND** Average Inflow < 0.48 **NO**

Stage 1: High Rock HWEL < NME minus 1 **AND** US Drought Monitor => 1 **NO**
**OR** High Rock HWEL < NME minus 1 **AND** Average Inflow < 0.41 **NO**

Stage 2: High Rock HWEL < NME minus 2 **AND** US Drought Monitor => 2 **NO**
**OR** High Rock HWEL < NME minus 2 **AND** Average Inflow < 0.35 **NO**

Stage 3: High Rock HWEL < NME minus 3 **AND** US Drought Monitor => 3 **NO**
**OR** High Rock HWEL < NME minus 3 **AND** Average Inflow < 0.30 **NO**

Stage 4: High Rock HWEL < ⅓ of NME minus CRWE **AND** US Drought Monitor => 4 **NO**
**OR** High Rock HWEL < ⅓ of NME minus CRWE **AND** Average Inflow < 0.30 **NO**

***Evaluation Criteria for Recovery (If Previous LIP Stage ≠ Stage -1)***

Recovery from this LIP will be triggered by any of the three following conditions:

- Condition 1: If all three triggers associated with a lower numbered LIP Stage are met on the first of the month, the LIP recovery will be a general reversal of the staged approach on the first of each month.

**OR**

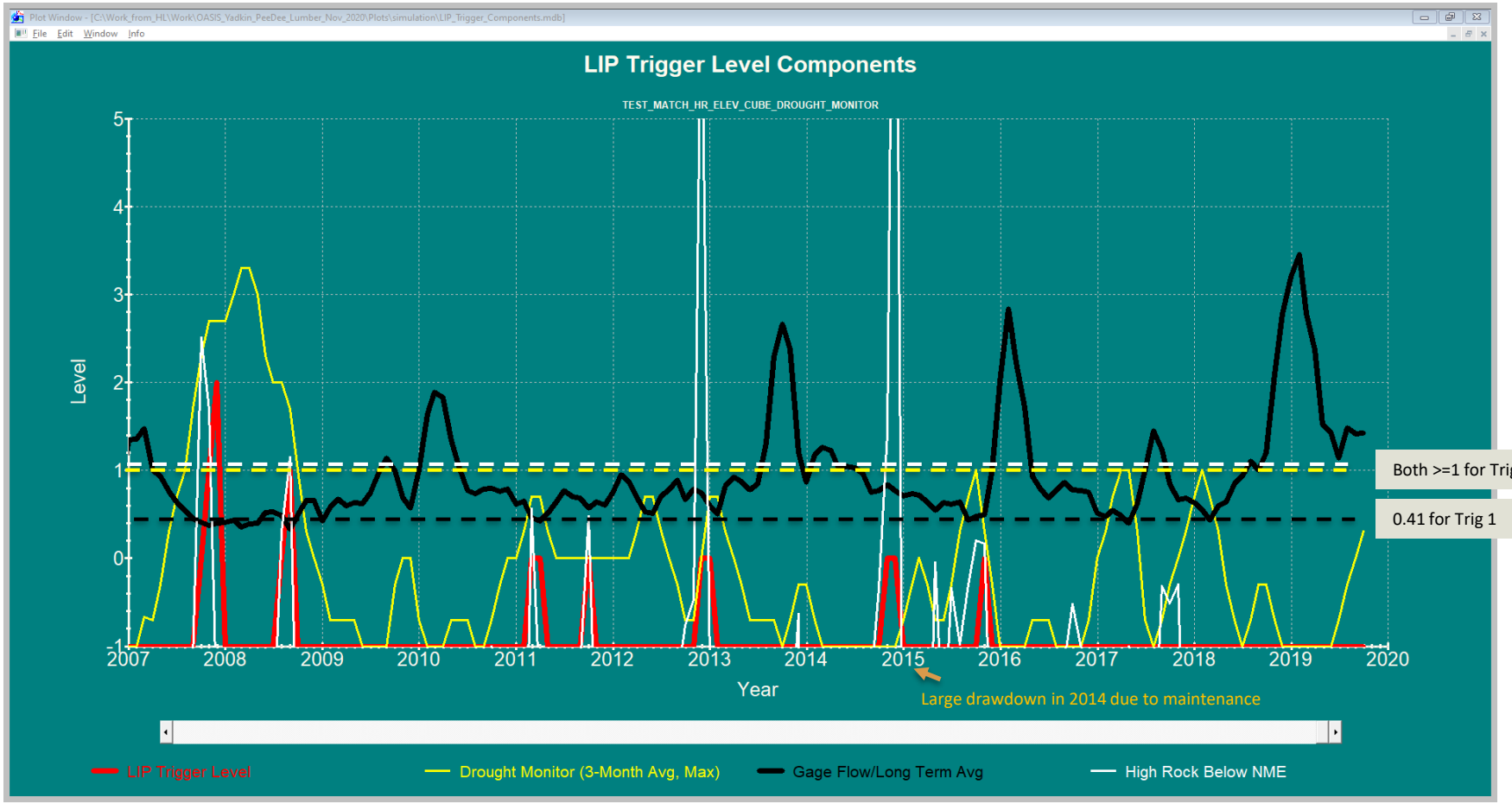
- Condition 2: If High Rock Reservoir water elevations return to at or above the NME PLUS 2.5 ft, the LIP will be discontinued immediately.

**OR**

- Condition 3: If High Rock Reservoir water elevations return to at or above the NME for 2 consecutive weeks, the LIP will be discontinued immediately.

http://cubecarolinas.com/wp-content/uploads/2019/12/2019-12-December-Check.pdf

# LIP (End of Month Assessment) – Matching HR Historic Elevation




Actual LIP levels:

Sep and Oct 2007: 2

Jul and Aug 2008: 0 and 1, respect.

Feb 2011: 0
Sep 2011: 0
Nov 2012: 0

Oct and Nov 2014: 0 (due to maintenance)

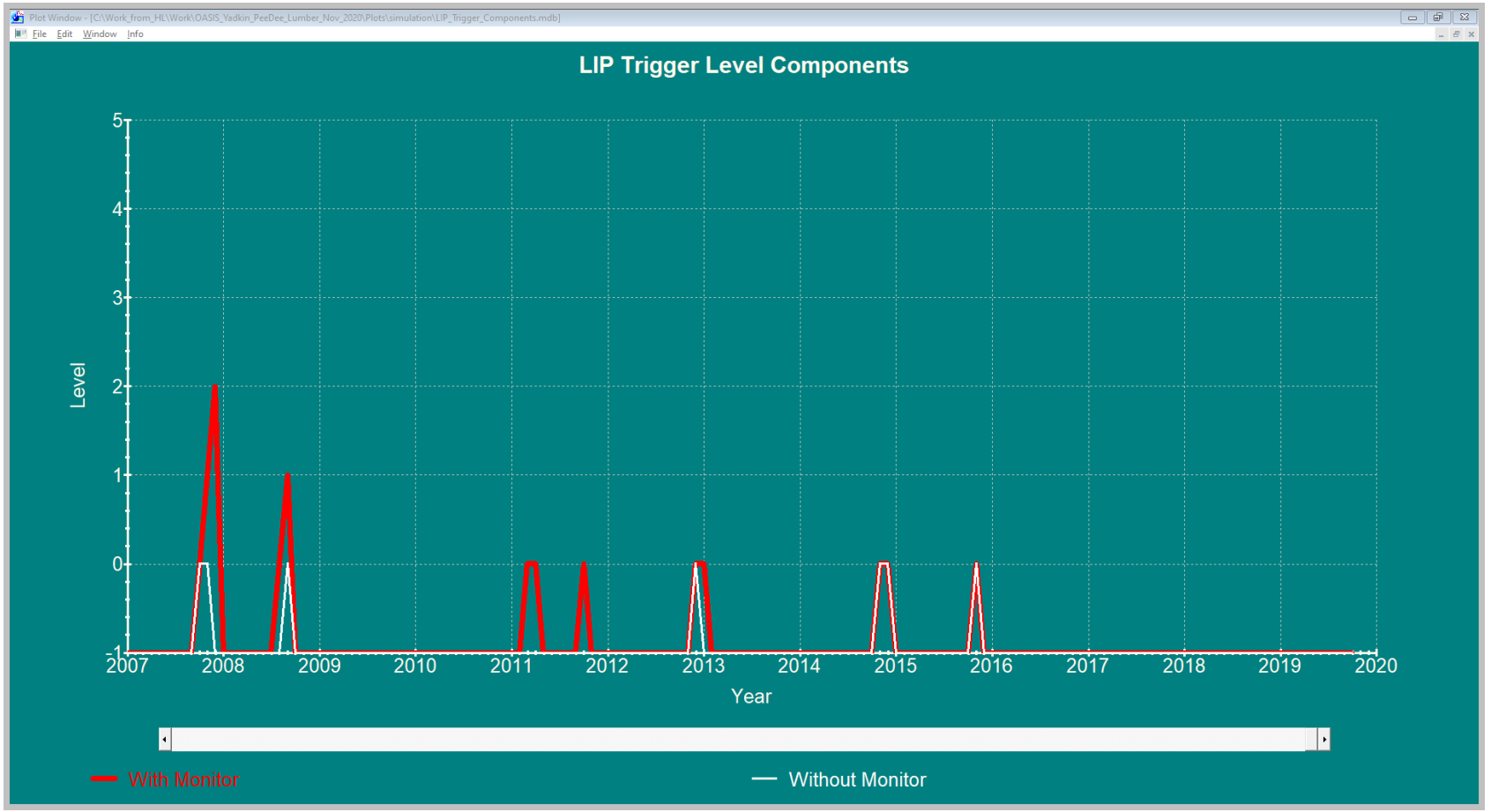
Oct 2015: 0

Both >=1 for Trig 1

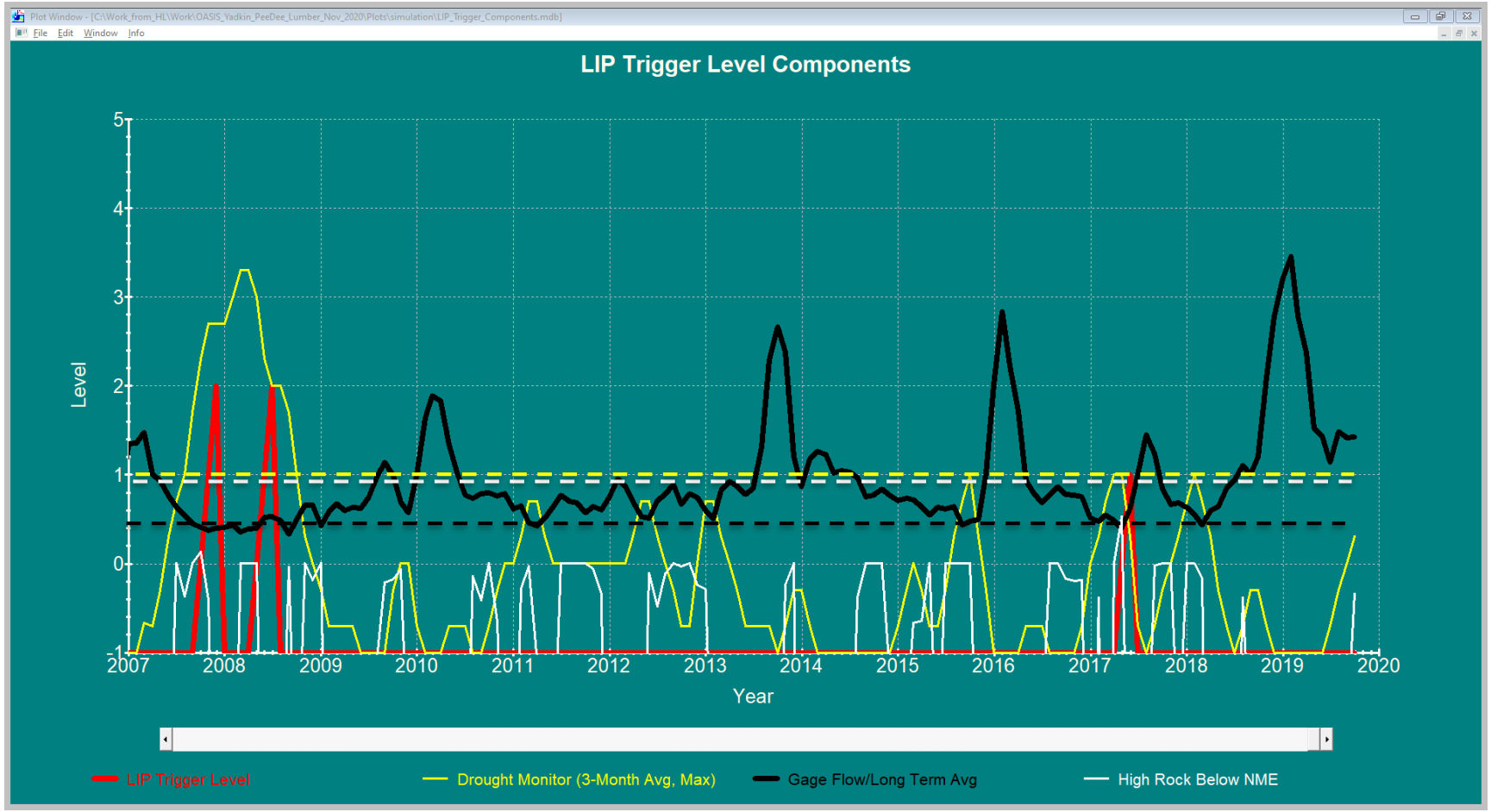
0.41 for Trig 1

High Rock operations post-2007 LIP issuance may have differed from post-2017 license issuance.
Timing of triggers might be offset by a month depending on when calculation is made.
Drought monitor 3-month average may differ from Cube's calculations (starting Feb 2007); Cube's used here except later when showing 2000 to 2007.

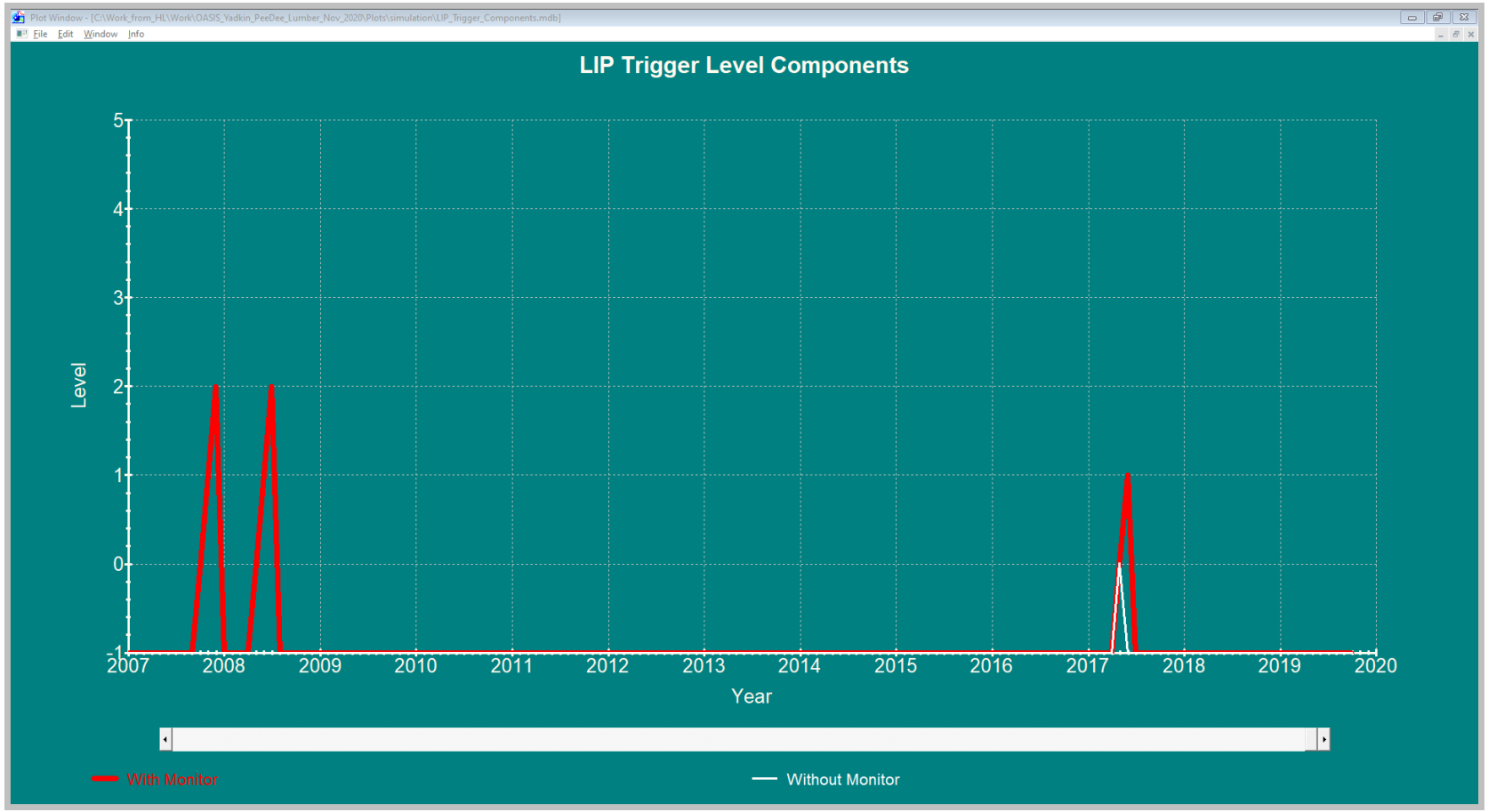
# Impact of Drought Monitor



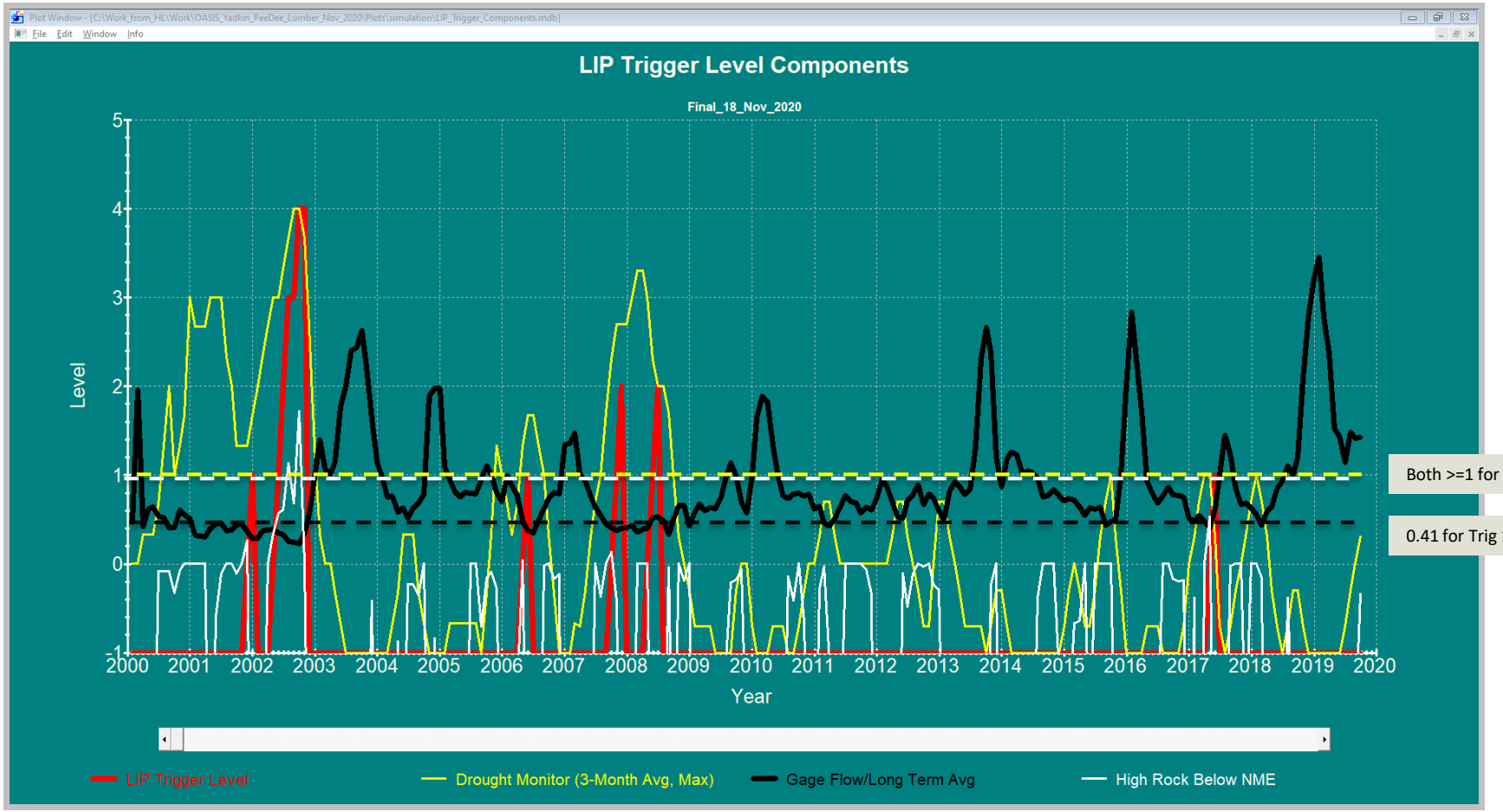
# LIP - Simulation



# LIP – Simulation (With and Without Monitor)



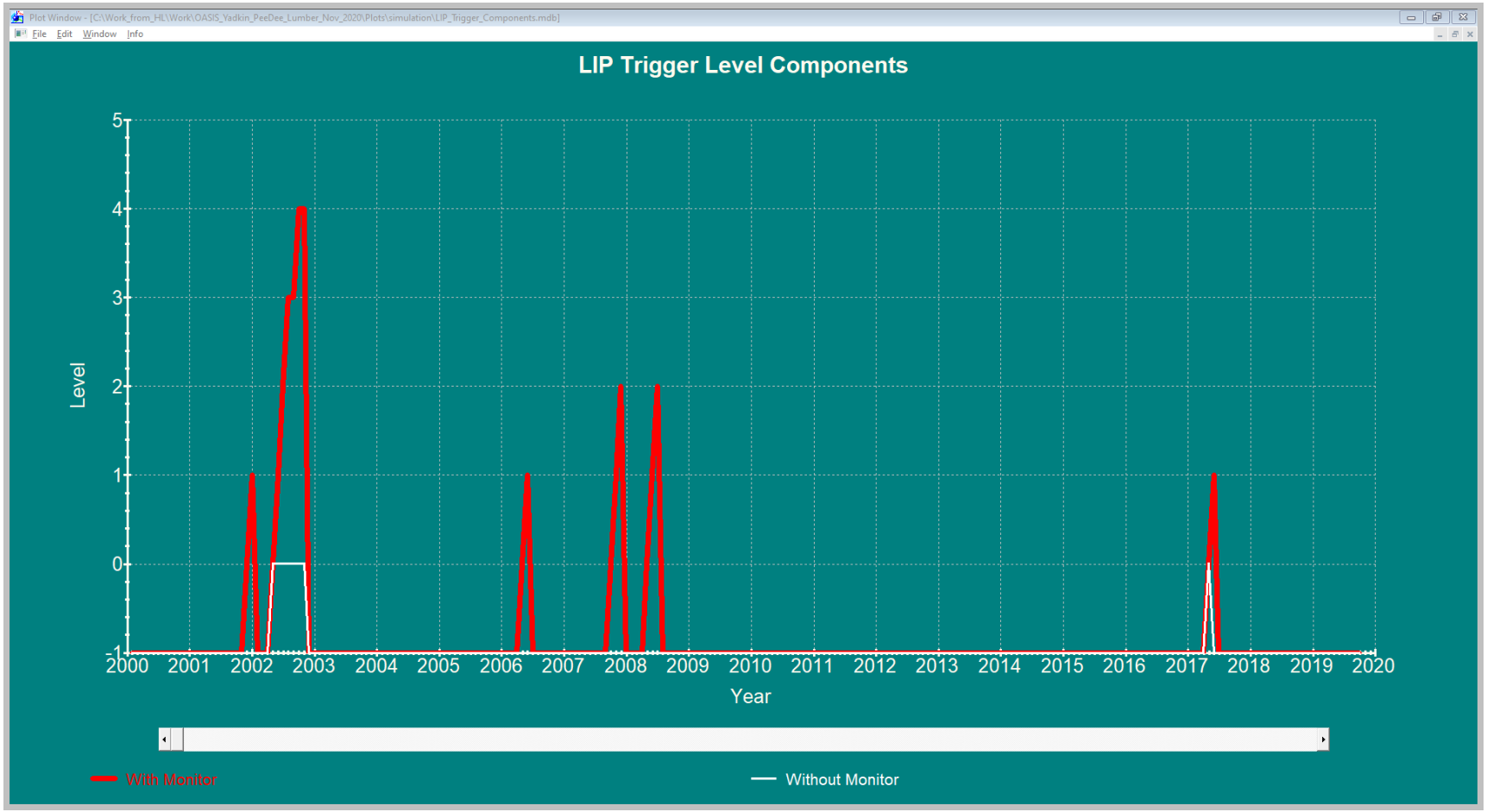
# LIP Simulation Back to 2000




Both >=1 for Trig 1

0.41 for Trig 1

# LIP – Simulation (With and Without Monitor)



# Impact of LIP on Flows

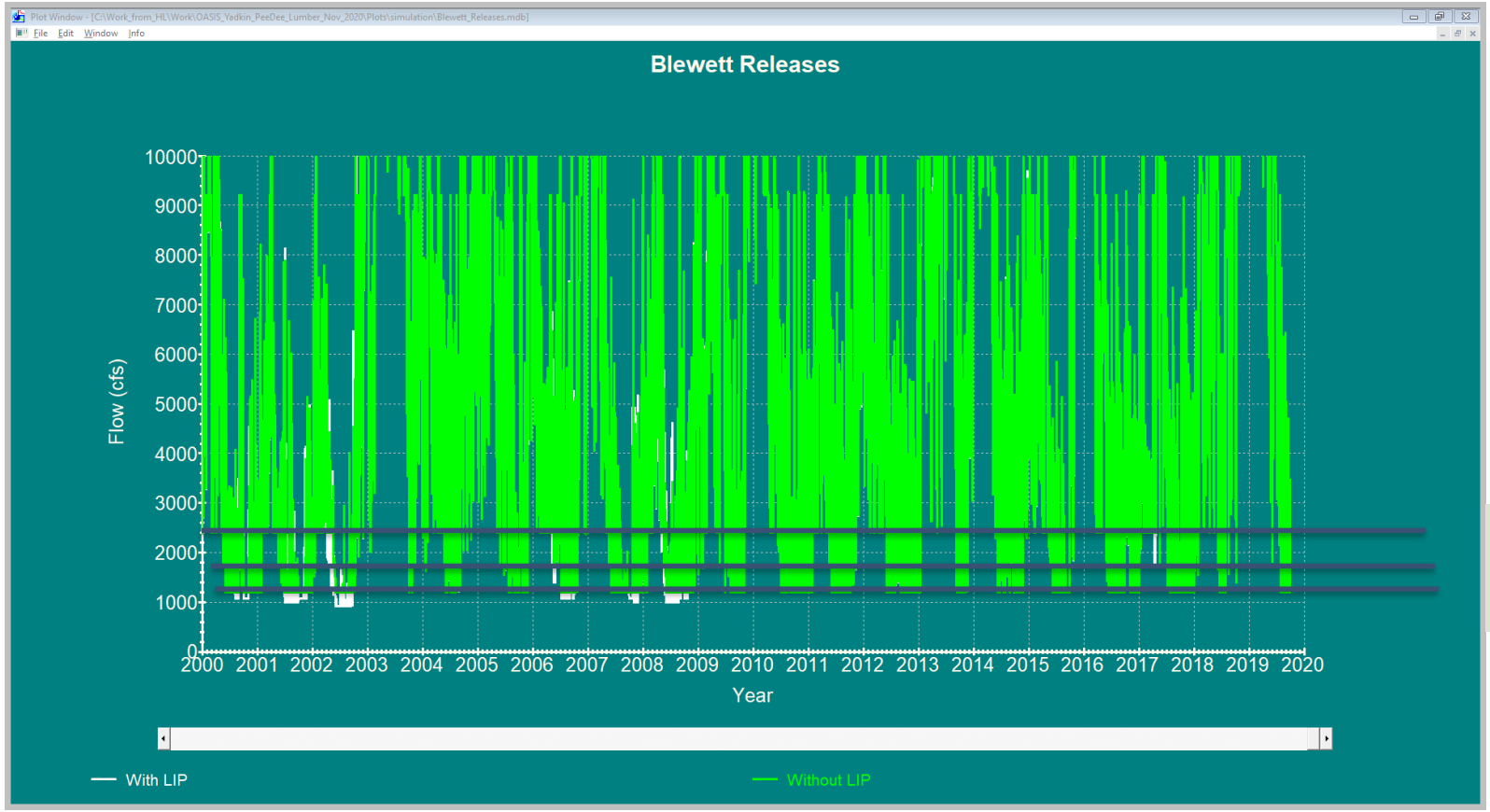

Normal = 2000 cfs (Feb 1 – May 15)

Normal = 1500 cfs (May 16 – 31)

Normal = 1000 cfs (rest of year)

LIP on is with the drought monitor; No LIP also includes no utility WSRPs on – all set by switch in constants table (drought plans on or off)

# Impact of LIP on Flows

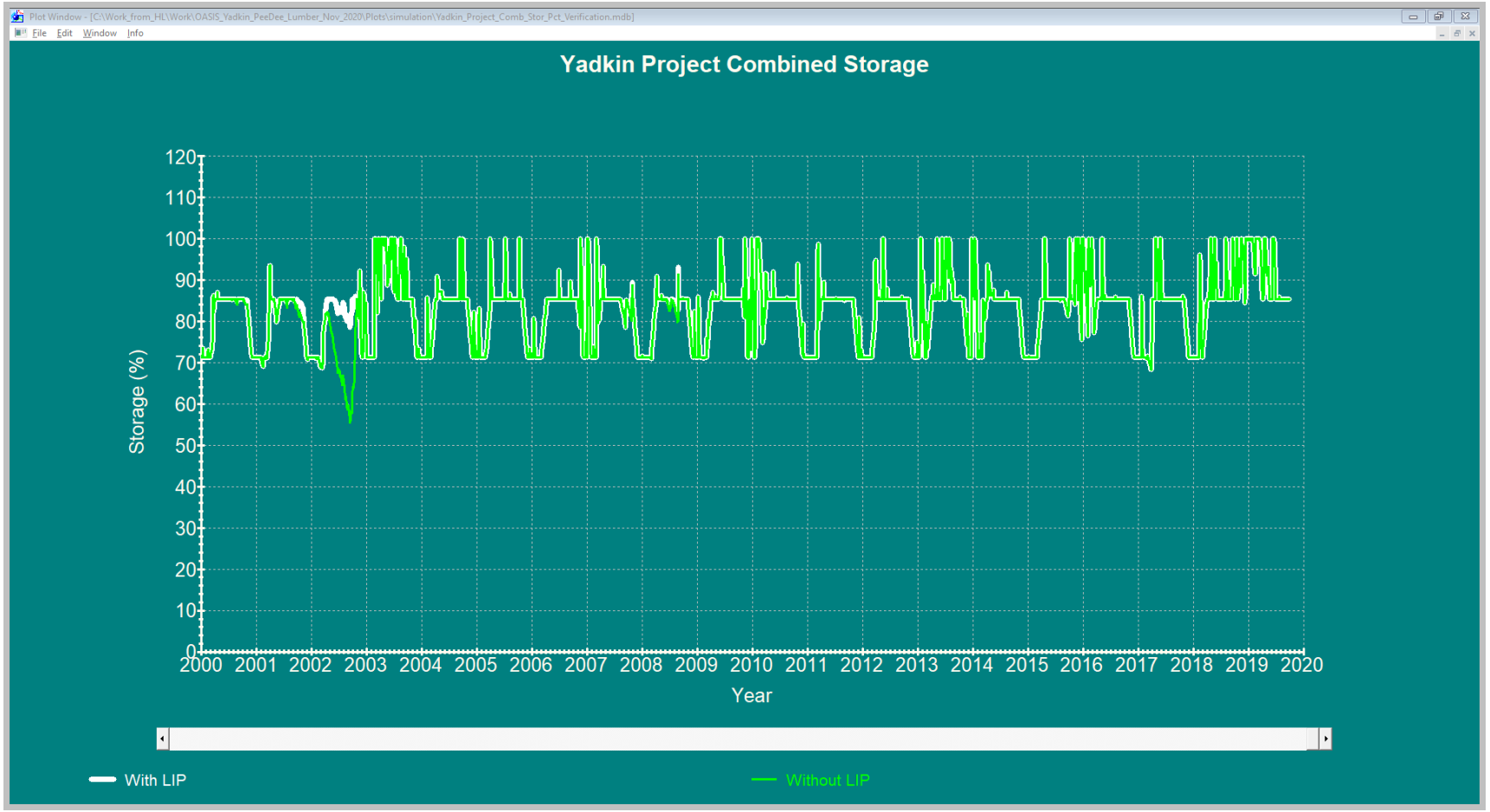



Normal = 2400 cfs (Feb 1 – May 15)

Normal = 1800 cfs (May 16 – 31)

Normal = 1200 cfs (rest of year)

# Impact of LIP on Storage



# Impact of LIP on Storage